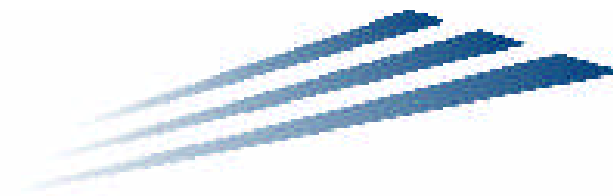


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## MOVEMENTS AND SETTLEMENTS OF HIGHWAY BRIDGE APPROACHES





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Research Report  
KTC-02-18/SPR-220-00-1F

## **MOVEMENTS AND SETTLEMENTS OF HIGHWAY BRIDGE APPROACHES**

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In cooperation with the  
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And

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## **ABSTRACT**

This report is a discussion of the bridge approach settlement or movement problem that is so prevalent in the United States. An explanation and/or description is given of the causes of these movements as described in the literature. A discussion concerning the cost to highway agencies is also given.

A review and discussion of current practices in the country is given . This includes construction practices on approach embankment foundations, the approach embankment itself, various types of approach slabs, types of abutments and end bents, and drainage around approach embankments and bridge ends.

A survey of all 50 states was conducted to determine the problems and practices in those states. Those results are summarized in this report. Additionally, a survey was conducted of all 12 highway districts in Kentucky to determine the differences in practice among those districts. Those results are given in Appendix B.

Finally, conclusions and recommendations on the apparent best practices are discussed.

## **I. INTRODUCTION**

### Explanation of Problem

The simple reason that settlement of bridge approaches relative to bridge decks is a problem is that this differential settlement creates a "bump" in the roadway, which is a serious problem from the user point of view.

From a motorists' perspective, this bump problem could be as insignificant as causing a compact disc to skip while driving, or significant enough to cause damage to the vehicle crossing the interface, or even be severe enough to cause the motorist to lose control of the vehicle. This all depends upon the severity of the elevation difference between the bridge approach and deck. Additionally, motorists face delays and inconveniences when a lane or lanes must be shut down to undergo bridge approach repairs.

From the transportation departments' perspective, a bump problem can lead to problems ranging from a lowered public perception of the department's work to major civil law suits. Both perspectives illustrate that this bump that is created is a very costly problem, in terms of both economic and punitive losses.

Another issue is the scale of the problem. As of 1995, there were 600,000 bridges across the United States. Of these, 150,000 had problems with bumps at bridge ends, resulting in estimated expenditures of \$100 million per year to remedy the problem. (Briaud et. al., 1997) Using these totals, the national average would calculate to nearly \$700 per year per bridge. In the Commonwealth of Kentucky, interviews with several DOT maintenance



engineers have lead to a rough estimate of \$1000 per year per bridge, slightly higher than the national average.

The solution(s) to the settlement problem must be able to reduce the size of the bump in a cost-effective manner, and have applications for a variety of cases since, as will be addressed below, there are a variety of potential causes.

One common solution popular currently is the use of concrete approach slabs. Approach slabs are reinforced concrete slabs that span the most severe problem area immediately adjacent to the bridge abutment. They act as a bridge between the bridge abutment and the approach pavement.

Figure 1 will provide an illustration of the components of a typical bridge approach system.

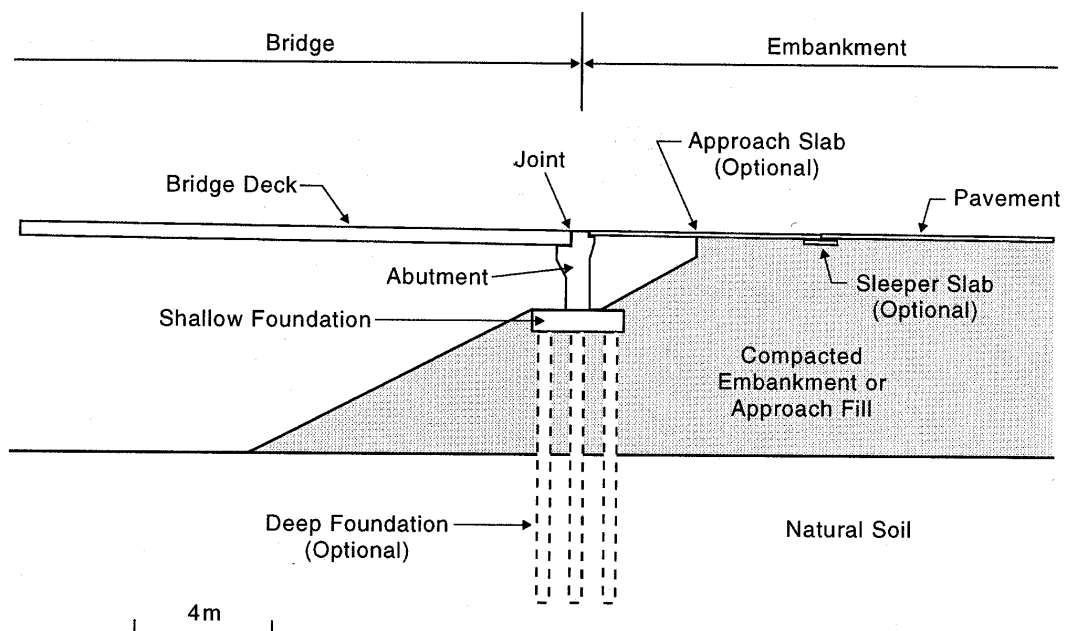


FIGURE 1 Elements of a typical Bridge Approach System. (Briaud et. al., 1997)

### Causes of Approach Settlement

The primary reason that “the bump at the end of the bridge” has been a problem on highways for such a long time is that there are so many factors that can contribute to settlement. There are, however, several commonly accepted factors that cause approach settlement to occur, and can be attributed as the factor that leads to the formation of bumps.

- I. ***Compression or Movement of Embankment Fill:*** Virtually all bridge approaches must be constructed on a fill embankment to allow the roadway to meet the elevation of the bridge. If a fill material is selected that is compressible over time or inadequate compaction is conducted, the traffic loads may cause the approach fill to compress and often lead to settlement (lowering the roadway elevation), while the bridge elevation remains constant. Typically, the settlement and/or compression of fill will approach a finite value and diminish over time. Also, embankment material must be resistant to slope failures and lateral displacements that would again lower the elevation of the roadway.
- II. ***Settlement or Movement of Foundation Soil Beneath the Embankment:*** Obviously, if settlement or displacement is present and not completely occurring in the embankment fill, the soil foundation for the embankment is experiencing settlement. The foundation settlement or movement is a result of both the dynamic traffic loads applied at the embankment surface and the static load of the embankment itself. As a result, lightweight fill materials may hold promise for reducing settlement by minimizing the load applied to the foundation soil.

With both cause I & II, the material used will likely be the native soil available in the area surrounding the bridge. The tremendous variability in engineering properties of soils makes addressing these problems a difficult

task. Therefore, widely applicable solutions to bridge approach problems will go beyond only soil concerns.

- III. ***Design/ Construction Problems:*** Often times, excessive settlement can occur simply because design and/or construction issues are not properly addressed such as the type of bridge abutment to be used, joint selection, the method of compaction, or simply that the approach is not constructed according to design. One particular issue common in this area is that the bridge and bridge abutment are often constructed before final compaction of the approach, making it difficult to get compaction equipment in place near the bridge end.
- IV. ***Poor Drainage:*** Poorly designed drainage systems can result in several problems, which can lead to settlement. First, if fill and foundation material reach a moisture content which is too high, the bearing capacity of the soil can be lowered allowing settlement or movement of support soil and lowering the elevation of the approach. Also, depending on the gradation of the fill and foundation soils, erosion can result beneath the approach roadway, also lowering the elevation of the approach.

### Cost Limitation

Since the problem is the responsibility of state highway departments, which operate under a defined budget, the cost of eliminating this problem is a significant factor. **The cost of any improved design methods must not exceed the life-cycle maintenance cost of existing practice.** When “the bump” becomes too large currently, highway maintenance crews will place an asphalt wedge tapering the change in elevation and returning the interface to a

smooth transition. The repair however will be temporary, however, and many high-traffic bridges can require wedging each year.

## **II. Literature Review**

A comprehensive literature review was conducted in preparation for this project to determine the current state of practice across the U.S.. While opinions varied on the severity of the problem and methods of minimizing the bump, previous studies seem to agree that approach settlement continues to be a troublesome problem in most states, and the causes have been identified in virtually all publications to be those presented in the introduction.

In perhaps the most complete recent publication, Briaud et. al. (1997) provides several widely accepted standards. The report highlights the most common construction errors that contribute to approach settlement as:

- Poor compactive effort of embankment fill and not anticipating settlement of foundation soil.
- Poor drainage leading to fill washout and development of voids under approach pavements.
- Poor joint development leading to abutment displacement via pavement growth, and not correctly accounting for temperature cycles.

Also presented are the following situations, which magnify the bump created:

- High embankments
- Bridge abutments on piles
- High average daily traffic
- Soft clay or soft natural silt soils
- High intensity rainstorms
- Extremes in temperature cycles
- Steep approach gradients

The following situations were reported by Briaud et. al. (1997) to minimize settlement:

- Abutment and embankment on strong soil
- A concrete approach slab of sufficient design
- Well-compacted or stabilized fills
- Appropriate fill material (to provide strength and resist erosion)
- Effective Drainage
- Low embankments
- Good construction methods and inspection
- Sufficient waiting period and/or surcharging between fill placement and paving

Figure 2 shows factors Briaud et. al. (1997) have developed as problems leading to the existence of a bump.

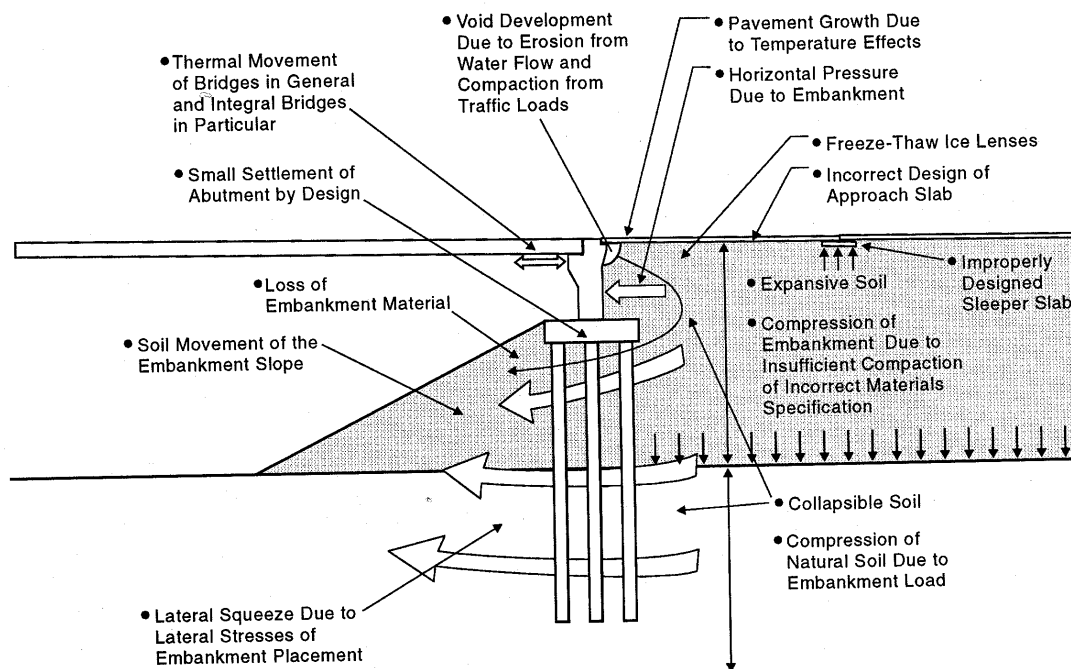


FIGURE 2 Problems leading to the existence of a bump. (Briaud et. al., 1997)

The final important element of Briaud's (1997) synthesis was the development of a "best current practice" list based on a survey of state DOT personnel:

1. Treat the bump as a stand-alone design issue and prevention as a design goal.
2. Assign the responsibility of this design problem to an engineer.
3. Stress teamwork and open mindedness among the geotechnical, structural, pavements, construction, and maintenance engineers. (Note: Often separate contractors are employed to construct the bridge and the bridge approach leading to "it's the other guy's responsibility")
4. Carry out proper settlement vs. time calculations.
5. If differential settlement is excessive, design an approach slab.
6. Provide for expansion/contraction between the structure and the approach roadway (fabric reinforcement, flow fill)
7. Design a proper drainage and erosion protection system.
8. Use and enforce proper specifications.
9. Choose knowledgeable inspectors, especially for geotechnical aspects.
10. Perform a joint inspection including joints, grade specifications, and drainage.

Wahls (1990) attributed settlement to the following sources:

- Foundation compression
- Embankment compression
- Poor compaction near the abutment because of restricted access
- Erosion of embankment at abutment face
- Improper drainage of embankment and abutment fill
- Approach slab design
- Abutment and foundation type

Also, Wahls (1990) suggested a differential settlement of 13mm (0.5 inches) is likely to require maintenance.

Stark et.al. (1995) conducted a survey of 1181 bridges in Illinois and discovered that 27% of the bridges had a significant bump ( $> 2$  inch), while only 15% showed no bump. This study also provided support for the idea that higher embankments are subject to greater settlements. Stark also provided the statement that rider discomfort across the bump was magnified if the approach gradient was in excess of  $1/200$ .

James et. al. (1991) states that approach roughness may be influenced by longitudinal pavement growth resulting from temperature cycles. In his survey of 131 bridges in Texas, it was determined that approaches with flexible pavements resulted in smoother transitions than rigid pavements. Another significant perspective put forth is that a large factor in interface settlement/ roughness is poorly designed and constructed expansion joints, which may create impact loads, thereby accelerating pavement settlement.

There has also been a great deal of work done within the Commonwealth of Kentucky concerning this problem. David Allen and Tommy Hopkins, of the Kentucky Transportation Center, have examined this problem extensively over the past thirty years. These have published the following reports:

- (Allen, 1988)- An analysis of six bridge approaches in Kentucky in terms of slope stability and finite element analysis. A theoretical approach model was used for finite element analysis and to predict approach pavement settlement. This report also contains a discussion of lateral movement of foundations and embankments.
- (Allen, April 1985)- For this report, a questionnaire was sent to all states concerning problems with bridge approaches. The report summarizes the responses along with specifications and standard drawings submitted by some states.



- (Allen, Oct. 1985)- This report was a case study of a foundation failure leading to the tilting of piers during the construction phase of a bridge approach in Northern Kentucky. It includes instrumentation of earth pressures and development of a factor of safety for the site, along with recommendations for remediation of the site problems.
- (Hopkins, 1973)- This report examined the causes of differential settlement between highway approach embankments and bridge decks, and abutment tilting. The discussion includes design, construction and maintenance practices in Kentucky at the time, slope inclinometer observations of embankments, slope stability analysis using Bishop's simplified method, results of shear strength testing for several sites, and suggestions for solutions.

### **III. Current Practice**

The evaluation of the current practice will be divided into five categories based on the components involved in bridge approach settlement. These categories will be, Approach Embankment Foundation, Approach Embankment, Approach Slab, Bridge Abutments, and Approach Drainage.

#### Approach Embankment Foundations

The behavior of the embankment foundation can be the single most important factor in the occurrence of bridge approach settlement. Should settlement in the foundation occur, settlement at the bridge interface is all but unavoidable. Also, problems that develop in the foundation post-construction will be the most difficult to repair, as they will occur 10 to 100 feet below the surface of a completed roadway.

Primarily, embankment foundation problems occur when the embankments are constructed on compressible cohesive soils. Non-cohesive soils present less of a problem since any compression occurs much more quickly, often before construction of approach pavements can begin. However cohesive soils (such as soft clays, silty clays, etc.) will display a more time dependent compression pattern, meaning corrections made to approach pavements caused by foundation problems will be drawn out over the period of the consolidation. Compounding this problem is the fact that cohesive soils have more variable strength parameters at various moisture contents than non-cohesive soils. Since bridges are very frequently constructed over creeks or streams, the soils surrounding the bridge, including the embankment foundations, are subject to wide variations in moisture content with seasonal changes. The result can be accelerated or magnified compression of the foundation. Cohesive soils are also much more likely to experience lateral plastic deformation, which could also contribute to approach settlement.

The settlement of soils typically consists of three phases: 1) initial, 2) primary, and 3) secondary (Hopkins, 1969). Initial settlement is the almost instantaneous settlement that occurs when a load is applied to a soil mass. The contribution of initial settlement to total settlement will decrease with a soils saturation level. (Partially saturated soils will have more initial settlement than saturated soils.) The initial settlement does not cause a problem in the formation of bumps, since it occurs prior to the construction of the approach pavement

Primary settlement is due to compression of the soil resulting from the gradual escape of water from voids of the loaded soil. (Hopkins, 1969) This phase accounts for the majority of the total settlement in soils. The primary settlement phase occurs faster in granular soils versus clayey soils due to small void ratios and high permeabilities in granular soils. The time period for the primary phase

can range from a few months in very granular soils to seven to ten years for some clays. (Hopkins, 1973)

The secondary settlement phase occurs as a result of a change in void ratio of a loaded soil after dissipation of excess pore pressure. (Hopkins, 1969) This phase occurs due to plastic readjustment of soil and water particles of a soil mass subjected to a continuously applied stress. The magnitude of secondary settlement is very small in granular soils, but can be as large as the primary settlement in highly organic or very soft clays.

These potential problems illustrate the need for substantial subsurface investigation prior to design and construction of approach embankments. Significant exploration is conducted to construct the actual bridge structure, and just as large an effort needs to be conducted for the approach embankment foundation. Figure 3 shows that, except at shallow depths (less than 10 ft.), the stress increase due to foundation soils will be significantly greater for embankment approach loadings than bridge structure loadings.

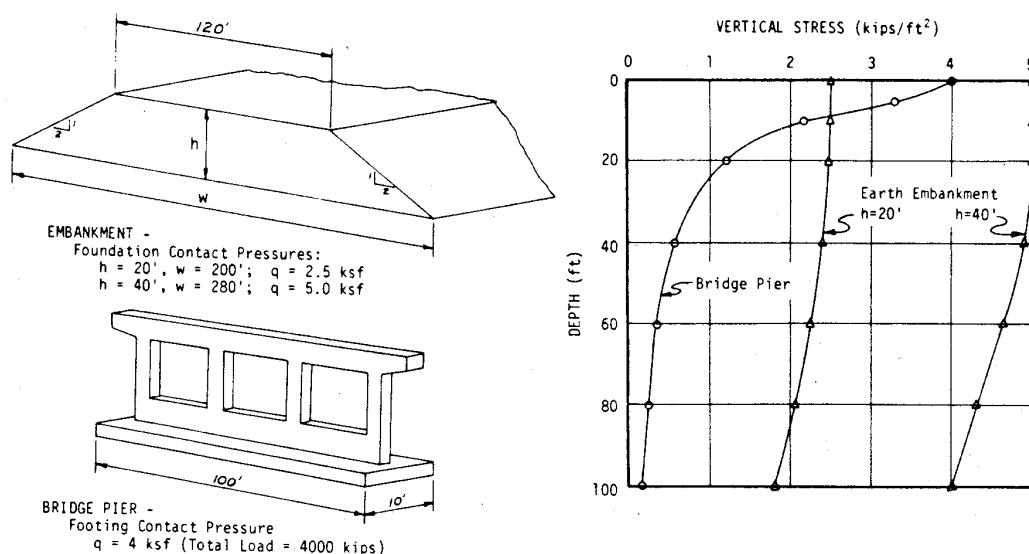


FIGURE 3 Comparison of vertical stresses beneath center lines of bridge piers and earth embankments. (Wahls, 1990)

Complete coverage of the foundation field must be conducted since soils are the most heterogeneous and diverse material encountered in construction, and soil conditions are likely to vary greatly, in just a matter of feet, due to sedimentation near bodies of water. Upon completion of adequate subsurface investigations, laboratory tests to estimate compression and consolidation potential and accurate calculations of anticipated settlements must be conducted to closely estimate the actual settlement that will occur in the foundation.

It is also important to ensure that shear failures do not occur in the foundation soils, resulting in lateral deformations, and surface settlement. Shear failures are likely to occur due to geological features such as a peat, organic or any weak seam of material in the stratigraphy of the site. Several stability analysis programs have been developed, such as ICES developed at MIT and STABL developed at Purdue University, which are currently used by State Highway Departments to examine foundation stability issues (Briaud et. al., 1997). This issue is typically not as great a problem in approach settlement as long as accurate calculations are done and prudent factors of safety are selected.

When situations do arise that the embankment foundation(s) will be inadequate, there are several alternatives to be considered. The choices include:

- Relocating the bridge, though this is usually the most costly alternative
- Reducing the loads applied to the foundation, by using lightweight aggregate for embankment fill, reducing the height of the fill, etc.
- Transferring loads through weak soil to more suitable layers below by piles
- Improving the properties of the foundation soil with chemical or mechanical stabilization.

One of the most effective methods for mitigating the effects of foundation settlement is by precompression of the foundation. In this process, the foundation is compacted, the embankment and perhaps a surcharge load are placed atop the foundation area, but construction of the approach pavement is delayed (up to one year) to allow settlement to occur prior to roadway construction.(Cotton et. al., 1987) Many state agencies are not willing to accommodate these precompression periods since the delay could cause significant problems in construction scheduling and drive initial construction costs higher.

Dynamic compaction, or vibro-densification, may also significantly accelerate settlement in foundation soils, but typically are more effective on non-cohesive soils (sands, gravels, etc.) that present less of a compression problem.

These methods may incur additional costs at the time of construction, but could significantly reduce the life-cycle maintenance cost if embankment foundations are known to be a problem.

### Approach Embankments

Approach embankments (particularly tall embankments) are usually most economically constructed with the most readily available fill material to the construction site. This however can often times provide an increased opportunity for approach settlement. Much like foundation soils, if approach embankments are constructed with soft, cohesive soils which are common to the site, a tremendous settlement potential is introduced which may lead to the bridge/approach interface “bump”. The cohesive soils are much more difficult to compact to their optimum densities and maintain compressibility potential for a longer period of time than more granular fill material. (Hopkins, 1973) As a

result, many highway agencies have begun to require only granular fill that can be better compacted and reach a maximum consolidation sooner to the time of placement. It should also be noted that the manner of compaction could play a very significant role in the settlement potential of the embankment. Jobsite inspectors should provide strict attention to ensure that proper compactive effort is applied to the fill material regardless of its composition.

The staging of the project construction can also hamper compactive efforts. Often, the bridge and bridge abutment will be constructed before the final approach fill. This is a logical assumption, but it makes compaction of the critical area most adjacent to the bridge more difficult since accessibility of compaction equipment is diminished. (Burke, 1987)

In addition to compression of approach embankments, lateral stability and shear strength is important to the overall stability resistance of the approach pavement. The lateral confining forces in approach embankments are significantly less than those in foundation soils. As a result, side slope design, material selection, and loading considerations all play a significant role in the final design for the embankment.

There are several methods to minimize the potential settlement and lateral movement in approach embankments. Probably the best method of embankment improvement is selecting high quality granular engineered fill, to be placed at least immediately adjacent to the bridge abutment. The engineered fill will predominantly be coarse granular material with high internal friction. Engineered fill will largely resist moisture sensitivity/ poor drainage, freeze-thaw action, long-term consolidation, and shear failures, which comprise the major drivers in approach settlement. A relatively new development is the use of flowable fill, a low strength flowable concrete mix, as backfill beneath and around the bridge abutments. This type backfill will experience virtually no

settlement, but can be significantly more expensive than available fill or engineered fill. Wrapping layers of granular backfill can also improve the quality of the embankment by preventing integration of engineered fill into natural soil and resistance against lateral movement. (Burke, 1987)

In addition to the use of select fill, a method of limiting lateral movements, is by utilizing geotextiles placed periodically during compaction of the fill to provide additional shear resistance. Also, reinforcing the slope surfaces to prevent erosion and maintain lateral confining pressures will significantly enhance lateral movement potential. (See Figure 4)

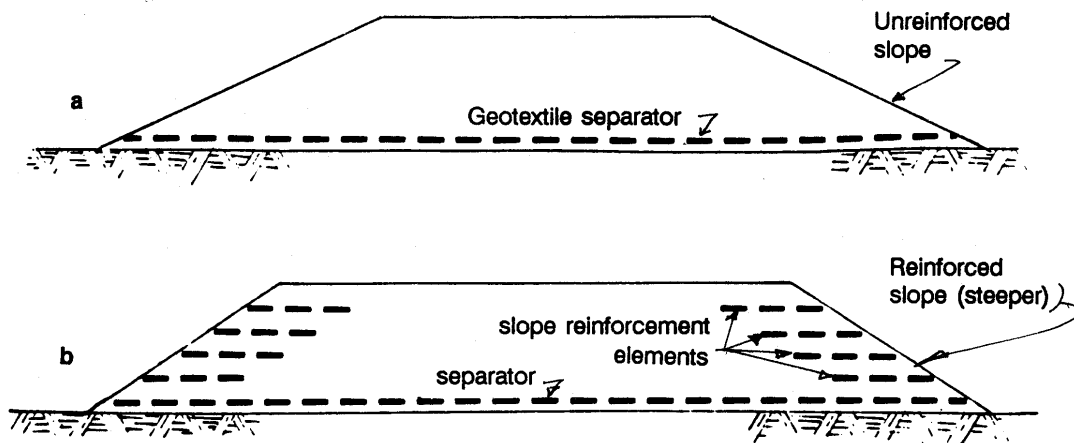
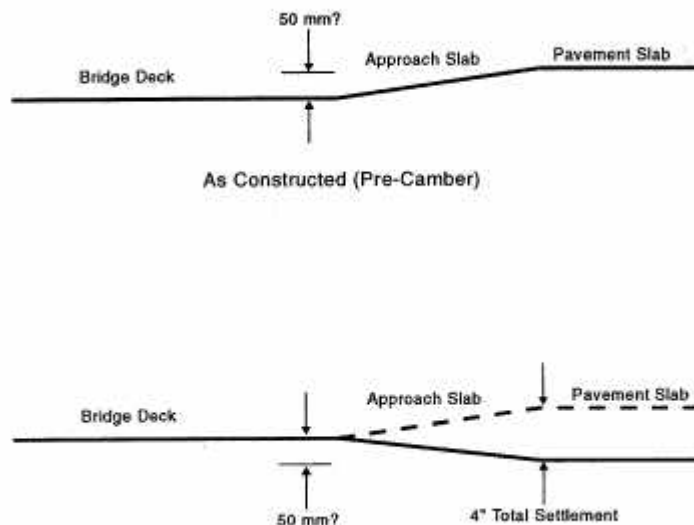


FIGURE 4 Schematic diagram of reinforced embankments. (Wahls, 1990)

Another approach to minimizing settlement effects is to construct the approach

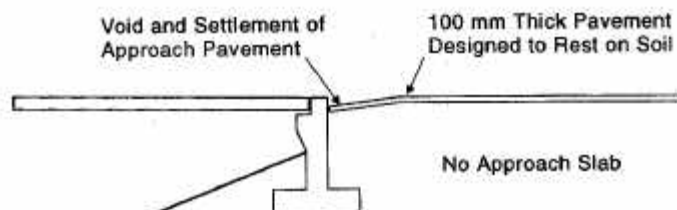
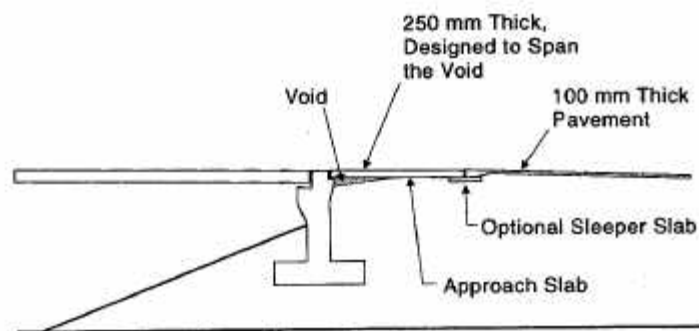


embankment with an initial camber, in conjunction with an approach slab that would settle out as the fill compressed. This approach is illustrated in Figure 5.

FIGURE 5 Precambering of approach pavement. (Briaud et. al., 1997)

### Approach Slab

One of the most popular settlement abatement techniques is the use of concrete approach slabs that span a small amount of settlement that may occur in the 15-20 feet adjacent to the bridge. (See Figure 6) The problem with approach slabs is that when settlement occurs, voids develop beneath the approach slab. If the slab is not designed with enough reinforcement to support the unsupported span length, cracking or complete failures may results and make the approach, or at least one lane, impassable to traffic. The difficulty involved in approach slab design is estimating the amount of settlement that will occur, which will dictate the unsupported length the slab must span. Also, the approach slab reinforcement design would need to be varied to accommodate the different traffic loads applied to specific roads. An overdesign of the approach slab may





be a slight over-expenditure, but an underdesign would result in maintenance costs and ride quality worse than those incurred without an approach slab.

FIGURE 6 Purpose of an approach slab. (Briaud et. al., 1997)

An additional component that is not universally applied in the implementation of approach slabs is the use of a sleeper slab (Refer back to Figure 6). A sleeper slab is a foundation slab placed transversally at the approach slab end opposite the bridge end. This sleeper slab permits the approach slab to settle with the approach embankment and prevent the sharp bump at the bridge.

Opinion is mixed as to the best vertical placement of the approach slab. Many believe the approach slab should be the riding surface from the approach pavement to the bridge, while others believe the slab should be placed below the riding surface, then a bituminous concrete overlay placed above the approach slab to act as the riding surface. The critics of each method would say that an approach slab surface pavement would simply move the “bump” from the bridge structure/ approach interface to the approach slab/ approach pavement interface. Also, some argue that approach slabs as surface pavement make maintenance, such as asphalt wedging, more difficult when slight improvements are needed in ride quality. Bituminous overlays are believed to present some problems though in that they rest on a stiffer material below and do not provide as long a life-cycle as concrete slabs only.

### Bridge Abutment Types

To simplify matters, a bridge abutment could be thought of as an end pier. It supports the end loads applied by the bridge superstructure, but unlike a pier, must also resist lateral movement due to embankment forces. Many abutment

designs exist and have been tried on bridges throughout the U.S., though a consensus has not been reached on the best type to minimize the “bump” problem. The predominant types of abutments used are closed abutments, perched abutments, spill-through abutments, integral abutments, and mechanically stabilized abutments.

Closed abutments are essentially tall walls that hold back the approach embankment and, therefore, are subjected to higher lateral earth pressures. Since closed abutments must be constructed before the approach embankment, at least in the area adjacent to the bridge end, it can be more difficult to bring large compaction equipment in to compact the embankment, leading to future potential settlement. (Chini et. al., 1993)

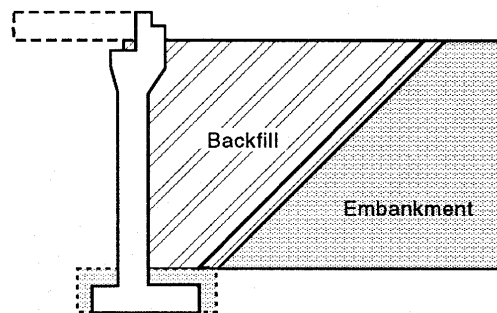


FIGURE 7 Typical Full Height Closed or High Abutment. (Wahls, 1990)

With perched or stub abutments the embankment can be constructed to the bottom elevation of the abutment, then backfill placed around the abutment to improve the ability to provide good compaction. Perched abutments are usually placed on spread footers or piling. An advantage of perched abutments is the lateral forces on perched abutments are the lowest of any of the mentioned types since it extends into the embankment less than the others. This suggests that perched abutments can be cheaper to construct, since they must resist smaller lateral forces and require less material, and may experience less lateral movement.

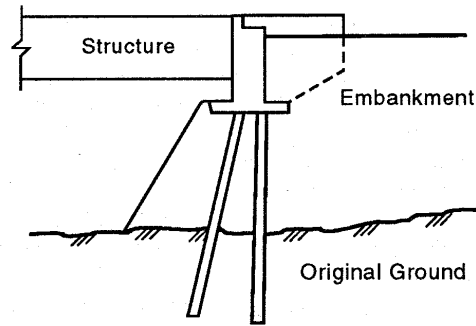
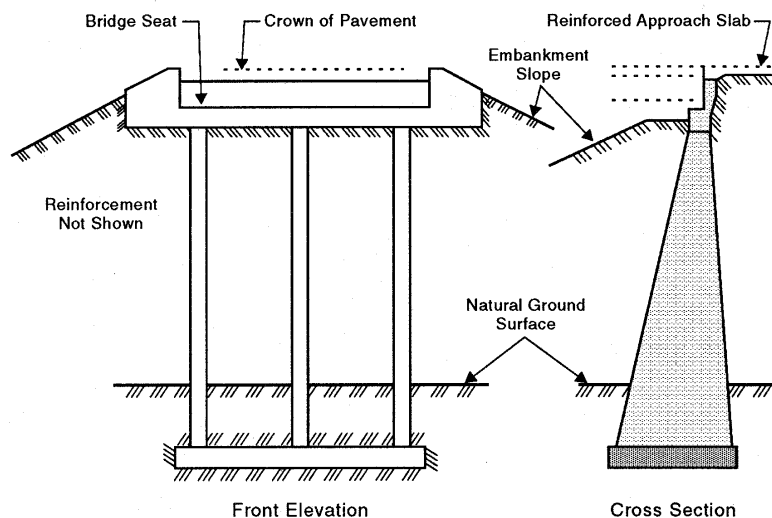


FIGURE 8. A Typical perched abutment. (Wahls, 1990)

Spill-through abutments are another type that must be constructed before the embankment is constructed. In this type, the abutment is constructed on columns, then the embankment is compacted on both sides of the columns. The spill-through aspect allows transmission of lateral forces through columns, which means the lateral forces on spill-through abutments will be less than those on closed abutments, but forces on columns add lateral forces beyond those of the perched abutment. The same problems with compaction of the embankment exist with spill-through abutments since the embankment must be constructed



after the abutment.

FIGURE 9 A Typical spill-through abutment. (Wahls, 1990)

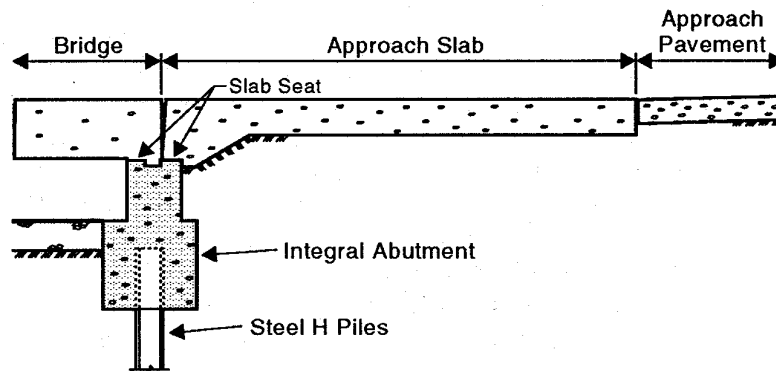


FIGURE 10 A Typical Integral Abutment. (Wahls, 1990)

Integral abutments, a variation on perched abutments and usually always placed on piles, are beginning to become more popular among highway agencies. An integral abutment gets its name from the fact that the bridge structure and abutment are rigidly connected as a single unit with no joints. The only joint in the approach using integral abutments occurs between the approach pavement and the abutment to allow for pavement expansion. (Sultani, 1992)

Transportation agencies have found that the elimination of expansion joints at this interface helps minimize construction and maintenance costs for the abutment. Since expansion joints have been eliminated between the abutment and the bridge structure, the abutment will normally experience some lateral movement in response to thermal stresses in the bridge deck. This lateral movement of the abutment has lead to cases of buckling and cracking in approach pavements, which will also contribute to a “bump” at the bridge end. (Sultani, 1992) Also, backfill material around the abutment is not elastic, so lateral deformations by the abutment can cause voids to develop allowing bridge rainfall runoff to enter and accelerate embankment erosion. Figure 11 shows examples of jointed abutments versus integral abutments.

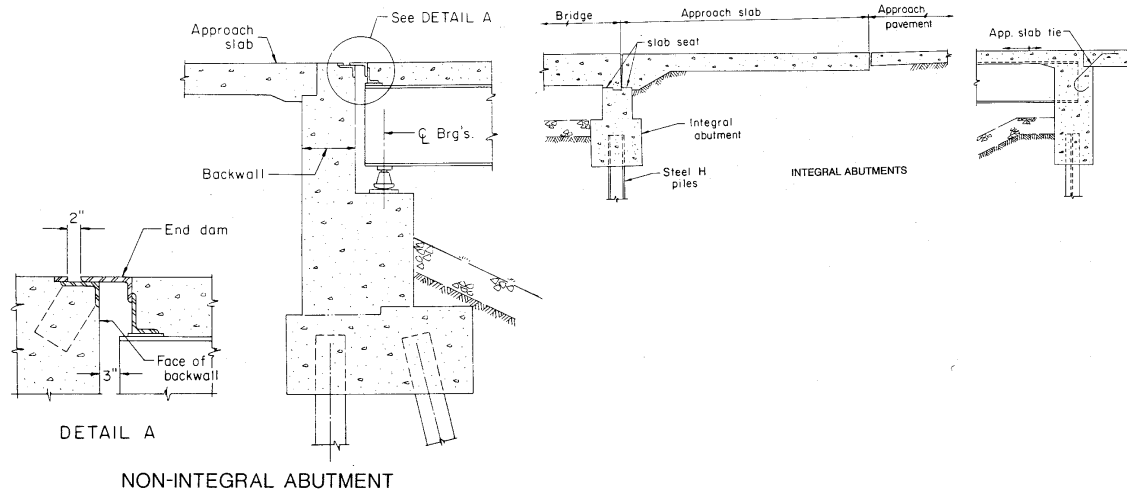


FIGURE 11 Typical Approach Slab/ Abutment Joints (Wahls, 1990)

Finally, mechanically stabilized abutments are similar to perched abutments except they are constructed atop mechanically stabilized backfill (MSB). The mechanical stabilization can be provided by geosynthetics, tie-back walls, etc. The MSB minimizes lateral loads in the embankment beneath the abutment meaning the abutment is less likely to experience lateral or vertical movement and allowing steeper slopes in areas where rights-of-way and clearances are restricted.

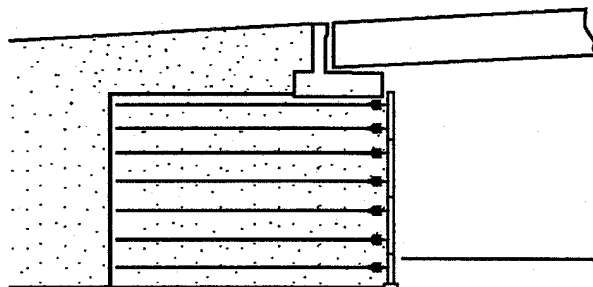


FIGURE 12 Typical Mechanically Stabilized Abutment (Wahls, 1990)

## Approach Drainage

The final key factor in minimizing the occurrence of “bumps” at the end of bridges is approach drainage. Water that collects on the bridge surface and approach pavements can do significant damage to the bridge approach. Water that seeps between the abutment and the approach pavement through joints or cracks can significantly erode the backfill beneath the interface. Without approach slabs, this will immediately induce settlement, causing a bump, and even with approach slabs, erosion can amplify the development of voids caused by compression of soils and lateral deformations. Whatever method is chosen for routing rainfall runoff, it is essential that water not infiltrate beneath the approach slab/ pavement and bridge abutment. Also, poor removal of water from side slopes can accelerate erosion on these areas and accelerate lateral spreading. Figure 13 indicates a range of most erodible soils.

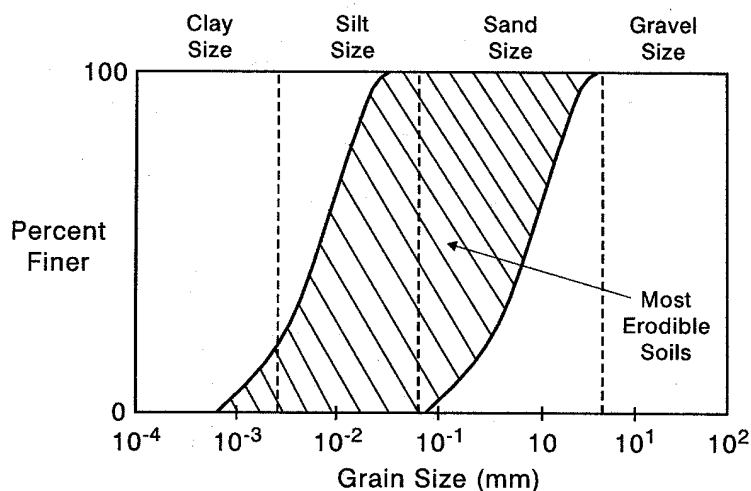


FIGURE 13 Example of range of most erodible soils. (Briaud et. al., 1997)

One final issue that has been tried is the construction of bridge structures on shallow foundations. With this principle, the bridge foundation will not be set to bedrock, but rather a spread footing will be placed atop foundation material similar to that which the embankment is founded on. This would theoretically result in uniform settlement of the bridge and approach embankment, and minimize the development of a “bump”. Most agree there is a possibility that this could improve the situation, but since bridges on shallow footings are likely to have a shorter life-span and more factors lead to the bump problem than just foundation settlement, this is not thought to be a very appropriate solution. Most trials have shown limited improvement in the bump severity.

Figure 14 shows good and bad design practice when disposing of water runoff.

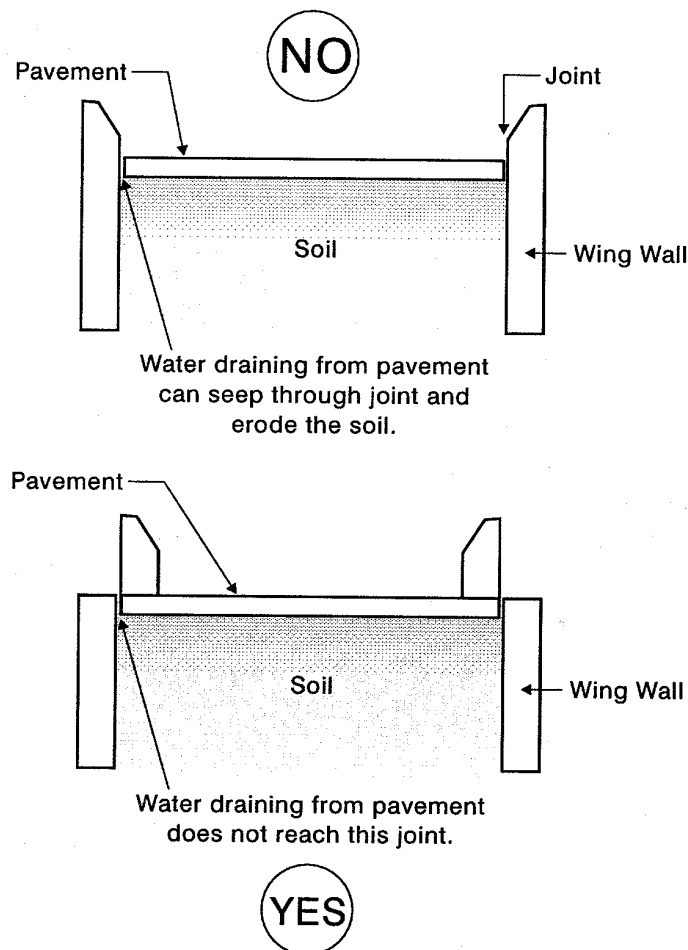


FIGURE 14 A Cross-section showing wing wall and drainage detail. (Briaud et. al., 1997)

### Results of a Survey of State DOTs

(Specific responses to each question are provided in appendix A)

For this report, a survey was conducted in conjunction with the Kentucky Transportation Center at the University of Kentucky. This survey was developed to assess the magnitude of the “bump” problem across the 50 states, and develop an understanding of current practices in the field.

- In response to the question, “Do you consider settlement of bridge approaches a major problem?”, nearly half of the respondents (24 of 50) agreed there was a major problem. Though this is not an extremely high percentage, only 14 of 50 answered no to this question (12 answered maybe, interpreted to mean settlement is a major problem in some cases). These responses do confirm the necessity for improvements in bridge approach design and construction and also provide an opportunity for learning by examining the practices of the states who aren’t experiencing major problems.
- Survey results on approach slabs showed that all but two states used some form of reinforced approach slab with mixed results. Of the 48 states that use approach slabs, 32 said they were successful, 1 (Kentucky) said they were not, and 15 answered maybe.
- Although 48 states use approach slabs, only 31 utilize sleeper slabs to disperse the load transmitted to the approach embankment. Of the 31



who use sleeper slabs, 14 say they are effective, 2 say they are not, and 15 are not sure.

- On the subject of integral abutments, 33 states use integral abutments versus 17 who do not. Of the 33 states who do use integral abutments, 26 believe they have performed well, while only 1 state (Arizona) believed they did not perform well. Recall that with integral abutments, expansion of bridge decks can lead to problems with abutment movement; a phenomenon made worse the longer the bridge is. A survey of the maximum length of bridge utilizing integral abutments found that Tennessee has a bridge of length 1175 feet with no problems, while the average longest bridge using integral abutments is around 300 to 350 feet.
- When asked if special procedures were used when backfilling around integral abutments and particularly end bents, only 21 of 50 states responded yes.
- When asked if abutments on spread footers were used, only 32 states answered yes, but of those 32, 29 believed them to be functioning successfully.
- As for the types of backfill material used around abutments, at least 38 states do use granular backfill, but as many as 17 states still use compacted soil to backfill around abutments. Three states use sand in some cases, and only 6 states use flowable fill with any regularity as abutment backfill.
- Only 21 states use filter fabrics to wrap and maintain confinement of granular backfill next to fine-grained soils.

- When asked if native soils with low bearing strengths were replaced at bridge approaches, 32 states answered yes.
- As an indicator of the prevalence of lateral and slope failures, a question was asked as to whether settlement was greater at the edges of the roadway versus nearer the centerline, only 7 answered yes, while 30 answered no, 9 didn't know, and 4 said the situation varied.
- An interesting question was whether or not warranties were required for bridge approaches. Of the 50 states, only Rhode Island requires such warranties, which are valid for a period of five years.
- When asked if preconsolidation and/or surcharging was allowed to occur prior to final construction, 23 states answered no , 12 answered yes and 15 answered sometimes. The time period for settlement to occur ranged for Minnesota's value of 1 to 3 months, to a maximum in California of 8 years. The most typical period was approximately 6 months. Surcharge heights ranged from 2 to 15 feet with an average of about 6 to 8 feet.
- The various maintenance techniques of each state are addressed in question 15 of the appendix.
- Drainage techniques for abutment areas are listed in question 16 and for bridge runoff are listed in question 17 of the appendix.
- Other methods of minimizing settlement problems are listed in question 8a.

- Finally each states' opinion of the most effective methods of preventing the “bump” are listed for question 20.

#### **IV. Evaluation of Current Practice**

##### Evaluation of Current Designs

Survey results from both this survey and that conducted by Briaud et. al. (1997) illustrate that approach slabs are widely considered successful when good pavement joints lead into them and they are designed with sufficient reinforcement to prevent cracking. Integral end bent abutments are performing as the best abutment type, though performance could be improved even more by improved backfill materials and procedures.

Drainage provisions, for the most part, are inadequate. Surveys of bridges in various states have found that the prevalence of erosion near abutment faces to be quite high.

Embankment design and construction quality varies greatly among states. Some states have implemented sufficient compaction and material selection specifications, while others lag behind. It is the opinion of the author that some states believe approach slabs are meant as a panacea for bridge approach settlement problems. While they do help minimize the problems associated with approach settlement, approach slabs cannot remedy design flaws.

##### Cost Analysis of Current Practice

As referred to previously, Briaud et. al. (1997) estimated that \$100 million is spent annually in the U.S. on repairing bridge approach problems. The money is usually spent on repairs will generally be applied to one of the following repairs:

- Asphalt Wedges- This is generally the least expensive method of repair for “bump” problems. When a bump develops an asphalt wedge (ranging in length from about 1 foot to 10 feet) can be placed to smooth the vertical transition. Incorporating the cost of equipment, labor, and material, **an asphalt wedge can usually be placed for only a few hundred dollars**. Most all states agreed in the survey however, that these wedges are a very temporary fix, in some cases lasting only months. The short life is due to the high impact loads these wedges receive as a result of the vertical transition.
- Asphalt Overlay- An asphalt overlay is essentially an extended asphalt wedge. In this procedure, the pavement is milled back, usually a larger distance than over which wedges are applied, and asphalt pavement is placed to smooth the transition. This procedure requires more labor and materials, more equipment in the form of a milling machine (about \$400/hr. to rent), and provides more of an interruption to traffic, resulting in **a cost of around \$4,000 per bridge end**, but usually lasts considerably longer than asphalt wedges. (A few years)

It should be noted that the application of the prior repairs will add dead load to the approach embankment, and may actually contribute to further settlement problems.

- Mud-jacking- This process involves injecting sand, grout, foam, or some other stabilizing material beneath an approach slab to fill in a void created by settlement. This can provide added support to approach slabs, to maintain the integrity of the slab. This process can, however, be messy, expensive, clog drainage systems near abutments, and may or may not fix the problem since it is difficult to control the material placement. **Costs can range in the low thousands of dollars**, with mixed success rates.

- Replacing Approach Slabs- When approach slabs do not receive adequate reinforcement, they may begin to crack and break apart. When this occurs, the replacement of approach slabs can be a costly maintenance procedure. A new approach slab will usually last upwards of five years, but **may have a cost in the range of \$10,000 per approach.**

In addition to these costs, one must include transportation agency's settlements resulting from law suits, injuries, damages, and complaints that result from the existence of a bump. These costs can be very difficult to determine and no data was discovered for this report. The result is an estimation for this report greater than that of Briaud et. al. (1997), probably in excess of \$200 million per year on the approximately 150, 000 deficient bridges in the U.S.

## V. Survey of Highway Districts in Kentucky

In addition to the survey that was sent to the states, the researchers also conducted personal interviews with maintenance and construction personnel in a number of the highway districts in Kentucky. To further supplement this information, a written questionnaire was sent to each of the districts. Numerous questions were asked in the areas of:

- The causes of the problems,
- Design methods,
- Prevention techniques,
- Maintenance activities,
- Maintenance costs,
- Drainage,
- Backfill materials.

Because of the wide variability of the answers, they are not summarized or discussed in the body of this report; however, the answers are shown in tabular and graphical form in Appendix B. In the table in Appendix B, a blank cell indicates that the district did not answer that question or the answer was unclear.

Also, in the graphs in Appendix B, an *Undecided* answer means the district was not sure about the question or left the question blank. The information in Appendix B is approximately 18 months in age (as of the writing of this report) and will not reflect any changes made in practice since that time.

## VI. Conclusions and Recommendations

The following recommendations are put forth by this report, as areas believed to have good potential toward future alleviation of bridge approach problems:

- Lowered Approach Slabs with Asphalt Overlays: In several states that do not classify settlement of bridge approaches as a major problem (New Hampshire for instance), concrete approach slabs are not the direct riding surface onto the bridge surface. Lowered approach slabs by many indications would not only provide a smoother transition from the time of completion (James et. al.), but also would be easier to apply periodic overlays and other maintenance measures.

**Additional cost:** Minimal, mainly a design consideration. The added cost of the asphalt thickness versus a subgrade material beneath the approach slab would be less than \$1,000 per bridge end.

- Require Settlement Periods and/or Surcharges Prior to Final Construction: Implementation of this idea would allow for much of the primary stage of settlement to occur, and therefore greatly minimize the amount of expected settlement upon completion. Again, scheduling conflicts make this an unwelcome addition to bridge specifications, but innovative project scheduling and cooperation of involved parties can minimize the impact of this delay, while dramatically cutting the maintenance costs after completion.

**Additional Cost:** Difficult to determine. Good project planning could provide virtually no added cost while providing maximum benefit.

- Design Maintenance Plans Concurrent to Construction Plans: Many states claimed the best way to minimize the presence of a bump is to

keep up-to-date with maintenance activities. If maintenance schedules are designed at the time of construction in addition to occasional required maintenance, pavement quality should be increased dramatically.

**Additional Cost:** Minimal --- would probably only require the development of several general plans to be assigned to each new bridge.

- Implement specifications for select fill adjacent to abutments: The states that have done this are the states that see their bridge approaches improving. The majority is using select fill, mechanically stabilized fill, or some other special fill requirements for abutment backfill and embankments.

**Additional Cost:** May add cost, but likely to be much less over bridge life than annual maintenance costs. An interstate project in Kentucky had 152 cubic meters of backfill with itemized costs of \$35.00 per cubic meter of Structure Granular Backfill or \$87.20 per cubic meter for flowable fill. This resulted in an added expense of no more than \$14,000 for the entire project over available borrow material

- Improve Drainage Designs On and Around Approaches: There is little argument as to the problems erosion near abutments and on approach slopes can cause, but there is a deficiency in the design methodology for handling drainage issues. Florida is a leader in roadway drainage and it comes as no surprise that Florida doesn't view approach settlement as a major problem. (The non-cohesive nature of many of Florida's soils also aids in this distinction) Mandatory drainage within the approach embankment, or at least at the edges of the embankment, and improved disposal of bridge runoff can help maintain a more



constant fill moisture content and minimize erosion, both helping reduce approach settlement.

**Additional Costs:** Not exceedingly high. Drainage pipes and materials can usually be added to construction plans for a fraction of the cost of the maintenance activities usually done.

- Require Bridge Approach Warranties: This may be a difficult idea to sell in some areas of the country, but bridge warranties would bring out the best of teamwork among all involved. Contractors would be impelled to closely review State designs and specifications and provide input on better design alternatives. Contractors would also have more of an impetus to perform quality construction techniques.

**Additional Cost:** Likely to be considerable, but with many warranties, none of the maintenance activities required currently would be paid for by the transportation agency for the warranty period. Many other roadway warranty experiments have showed that warranties can significantly reduce maintenance expenditures.

- Reduce the Side Slope of Embankments: When feasible, gentler slopes are more resistant to settlement and lateral movement in both the embankment and the foundation. Allen conducted a theoretical finite element analysis for six bridge approaches in Kentucky and verified this theory.

**Additional Cost:** Minimal, assuming no clearance problems and availability of fill material.

- Improve Approach Slab Design: An approach slab that is longer and has stronger reinforcement would help to minimize the problems from settlement. Increasing the length of the approach slab will decrease the total change in elevation experienced by passing vehicles and extend

the length over which the change in elevation occurs. Stronger reinforced slabs would provide more resistance to unexpected unsupported span lengths, basically increasing the allowable settlement.

**Additional Costs:** Minimal, mainly a design consideration. Likely that the only added cost is that of slightly more steel and concrete

The recommendations provided are practical solutions in that they will do little to add to the costs of constructing the bridge, and should provide a more economical life cycle cost for bridges in addition to minimizing the impact of the bump at the end of the bridge. The result should be smoother transitions meaning a more safe and comfortable ride for motorists.

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**Appendix A**  
**Survey Questions Sent to the States**



### **Movement and Settlement of Highway Bridge Embankments**

***Thank you for agreeing to participate in our survey. Please fill out this survey and return it in the enclosed stamped envelope by June 15th, 2000.***

1.) Do you consider settlement of bridge approaches a major problem? ☐Yes ☐No ☐Maybe

2.) Do bridge approaches in your state use some form of reinforced approach slab? ☐Yes ☐No

2a.) If so, please describe the reinforced approach slab  
(heavily reinforced, self-supporting slab, etc.)

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2b.) Are reinforced approach slabs successful? ☐Yes ☐No ☐Maybe

3.) If reinforced slabs are used, how long are they? \_\_\_\_\_ft.

4.) Are integral end-bents used in your state? ☐Yes ☐No

4a.) What is the maximum bridge length in your state utilizing integral end-bents?  
\_\_\_\_\_ft.

4b.) Have integral end-bents performed well? ☐Yes ☐No ☐Maybe

5.) Are special procedures used when backfilling around end-bents? ☐Yes ☐No

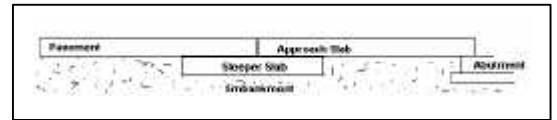
5a.) If so, what types of procedures? \_\_\_\_\_  
\_\_\_\_\_

6.) What types of backfill material are used?  
Granular ☐ Compacted Soil ☐ Others \_\_\_\_\_  
Sand ☐ Flowable Fill ☐

7.) Are Filter Fabrics used between granular backfill and fine-grained soils? ☐Yes ☐No

8.) Are any other methods used to minimize settlement problems? ☐Yes ☐No

8a.) If so, Describe the methods\_\_\_\_\_



\_\_\_\_\_

\_\_\_\_\_

9.) Have sleeper slabs been used in your state? ☐Yes ☐No

9a.) Are they successful? ☐Yes ☐No ☐Maybe

10.) Are abutments on spread footers used? ☐Yes ☐No

10a.) Are they successful? ☐Yes ☐No ☐Maybe

11.) Are native soils with low bearing strengths (silts, expansive clays, etc.) replaced at bridge approaches? ☐Yes ☐No

12.) Where settlement is occurring, is settlement greater at the outer edge of the roadway vs. nearer the center line? ☐Yes ☐No

13.) Does your state require warranties for bridge approaches? ☐Yes ☐No

13a.) How long are the warranties valid?

\_\_\_\_\_yrs

14.) Does your state place a surcharge on the approach to allow settlement to occur prior to final construction? ☐Yes ☐No



14a.) If so, for how long? \_\_\_\_\_ yrs. \_\_\_\_\_ mos.

14b.) Is there a typical surcharge height? \_\_\_\_\_ ft.

15.) What types of maintenance techniques are used to repair settlement at approaches?  
(asphalt wedges, jack-up slab and insert foam, sand, or cement beneath, etc.) What  
are the benefits and disadvantages of these techniques?

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16.) What kinds of drainage techniques are used behind the bridge abutments?

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17.) What drainage methods are used to dispose of bridge runoff?

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18.) Are paved ditches used near bridge approaches? ☐ Yes ☐ No

18a.) If so, are they successful? ☐ Yes ☐ No ☐ Maybe

19.) Are drainage outlets located near a bridge positioned at:

☐ The front or top of the bridge slope

☐ The bottom of the bridge slope

20.) What method(s) have you found to be the most effective in minimizing movement and settlement on bridge approaches?

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**Additional Comments:**

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Name: \_\_\_\_\_

Job Title: \_\_\_\_\_ E-mail Address: \_\_\_\_\_

Mailing Address: \_\_\_\_\_

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**Appendix B**

**Summary of Survey Results Sent to the  
12 Highway Districts in Kentucky**

# Summary of Responses from the Survey of the 12 Highway Districts in Kentucky

District	1	2	3	4	5	6	7	8	9	10	11	12
<b>PROBLEM CAUSES (BY)</b>												
Is there a major problem?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Is settlement uniform across roadway?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fill/Not-Fill Settlement (Deep Settlement)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fills are getting larger and larger, higher	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Basal Materials Settle	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Poor Compaction	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Cost factor - Construction Related	N	N	N/A	Y	N	Y	Some/Other	Y	Y	Y	Y	Y
Movement of Structures Road, turned on weak soil	N	N	N	N	N	N	N	Y	Y	Y	Y	Y
Expansion & Contraction	N	N	N	N	N	N	Y	N	Y	Y	Y	Y
<b>DESIGN METHODS</b>												
Does your district have any input into the design?	Y	Y	Some	Y	Y	Y	Y	Y	Y	Y	Y	Y
Revised Approach Slopes - Do you use them?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Are Approach Slopes working?	Y	N	Y	N	Some	N	N	N	N	Some	Y	Y
Major Voids Underneath?	N	Some	N	Y	Some	Y	Y	Y	Y	Y	Y	Y
Drift, blowing cause problems?	Y	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Is 25' a sufficient length?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Do you let them do the adjustment?	N	N	N	N	N	N	N	N	N	N	N	N
Do you let them into the subgrade?	N	N	N	N	N	N	N	N	N	N	N	N
Do you think they should be let in?	N	N	Y	Maybe	Maybe	Y	Y	Y	Y	Y	Y	Y
Integrate End Berms - Do you use them?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Are specs on how to fill sufficient?	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Fill/Berms below or inside the subgrade?	End-Berm	N/A	N/A	Wedge	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Adjustments - Do you use them?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Are specs on how to fill sufficient?	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adjustments - Solid Void	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adjustments - Soil Through	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Initial types do you prefer?	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some	Some
Adjustments with Spaced Filler	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
At what depth do you switch from spaced filler to base?	10'	N	10'-12'	20'	Y	Y	Y	Y	Y	Y	Y	Y
Do the spaced fillers work?	N/A	Y	N	Y - Or Solid Filler	Y	Y	Y	Y	Y	Y	Y	Y
Sleeper Slabs - Do you use them?	N	Y	N	N	N	N	N	Y	N	N	N	N
Do they work?	N/A	Y	N/A	N/A	N/A	N/A	N/A	Y	N/A	N/A	N/A	N/A
<b>PREVENTION TECHNIQUES</b>												
Sanitary Seal 18 years	N	N	Y	N	N	N	N	Y	N	N	N	N
Waterproofing (ELL)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Groutch Impregnation	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Self-Healing	N	Y	N	N	Y	N	N	N	N	N	N	N
Place Approach Slab Below Grade	N	Y	Y - 5"	N	N	N	N	Y	Y	N	Y	Y
Does it work?	N/A	Y	Y	N/A	N/A	N/A	N/A	Y	Y	N/A	Y	Y
Should Wing Walls Be Brought Back?	N	Y	Some	Y	Y	Y	Y	Y	Y	Y	Y	Y
Earth Walls (MSE)	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Do they work?	N/A	Y	N/A	Y	Y	Y	Y	Y	Y	Y	Y	Y
Road Demolition on Embankment and Approach	Y	Y	Y - 1"	Y - 2"	Y	Y	Y	Y	Y	Y	Y	Y
Pave Over Bridges	Y	N	N	N	N	N	N	N	N	N	N	N
<b>MAINTENANCE</b>												
Do you do a lot of maintenance?	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Avg
Reactive Program?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Mud Jacking/Slab Jacking	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Does it work?	Y	N	N/A	Y	N	N	N	Y	Y	Y	Y	Y
Grout Injection	N	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Does it work?	N/A	Y	N/A	Y	Y	Y	Y	Y	Y	Y	Y	Y
Sand Injection/Sand Slurry	N	Y	N	N	N	N	N	N	N	N	N	N
Does it work?	N/A	Y	N/A	N/A	N/A	N/A	N/A	N	N/A	N/A	N/A	N/A
Wedge	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Does it work?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Mud and replace?	Y	Y	Y - 1"	N	Y	Y	Y	Y	Y	Y	Y	Y
Does it work?	Y	Y	Y	N/A	Y	Y	Y	Y	Y	Y	Y	Y
<b>MAINTENANCE COST</b>												
Total Estimated Cost (1 BRIDGE PER 1 PAVING MILE)	\$1,000		\$1,000	\$1,000								\$1,000
What length?	25-50		25-50	100								
<b>DRAINAGE</b>												
4" Perforated Pipe	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
3" Perforated Pipe	N	Y	Y	N	N	N	N	Y	N	Y	N	N
Do you wrap the pipe or use a sock?	Some	Y	Some	Y - Sock	Y	Some	Some	Some	Some	Y	Y	Y
Wrap the length	Y	Y	Some	Y - Sock	Y	Y	Y	Y	Y	Y	Y	Y
Fill Material Used Around Pipe?	Granular	\$2.07	Granular	Gravel	Granular	\$13.07	Granular	Stone	Granular			
Does this system work?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Do Manholes work?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Edge/Accessories of pavement	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Do they work?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
What kind of drains are in the roadway?	Fin	Which	Fin	Which	Both	Y	Match slope	Fin	Y	N	N	N
Outlet Locations at Bottom of Slope?	Y	Y	Y	Pavement top	Bottom	Y	Match slope	Top/Bottom	Y	N	N	N
Perforated Drainage?	Y	N	Urban only	N	100%	N	N	N-10% work	Y	N	N	N
Drainage Blankets	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Blanket at Approach Slab?	N	N	N	N	N	N	N	N	N	N	N	N
Concrete Treated Drainage Blanket?	N	Y	N	N	N	N	N	N-10% work	Y	N	N	N
Does it work?	N/A	Y	N/A	N/A	N/A	N/A	N/A	N-10% work	Y	N	N	N
Asphalt Treated Drainage Blanket?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Does it work?	Y	Y	N/A	Y	Y	Y	Y	Y	Y	Y	Y	Y
Routine maintenance on the drainage system?	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	Y
Do you think bridge and drainage is working?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
<b>BACKFILL MATERIALS</b>												
Granular Number 57	N	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Unwrapped	N	N	Y	Y	Y	Y	Y	Y	Some	N	N	N
Wrapped	N	Y	N/A	N	N/A	N	N	Y	Some	Y	Y	Y
Price of Gravel 57 or Crushed 57	N/A	\$17.00/TON	\$20.00/TON	\$14.00/TON	\$10.00/TON	\$70.00	\$100.00	\$120.00	\$100.00			
Cost of Material?	N/A	\$17.00/TON	\$20.00/TON	\$14.00/TON	\$10.00/TON	\$70.00	\$100.00	\$120.00	\$100.00			
Granular Number 2 - Unwrapped	Y	Y	N/A	N	N	N	N	Y	N	N	N	N
Granular Number 2 - Wrapped	Y	Y	N/A	N	N	N	N	Y	N	N	N	N
Granular 2, checked w/ 57 - Unwrapped	N	N	N	N	N	N	N	N	N	N	N	N
Granular 2, checked w/ 57 - Wrapped	Y	N	N/A	N/A	N	N	N	N	N	N	N	N
Granular 55	Y	Y	N	N	N	N	N	N	N	N	N	N
Granular 3	Y	Y	N	Y	Y - Earth	Y	Y	Y	Y	Y	Y	Y
Granular 410	N/A	N/A	N	N	N - Earth	N	N	N	N	N	N	N
Granular 3	Y	Y	N	N	N	N	N	N	N	N	N	N
Wedge Material - Type 4 Fabric	Y	Y	Y	Y	N/A	Y	N/A	Y	N/A	Y	N/A	N/A
Does it work?	Y	Y	Y	Y	N/A	Y	N/A	Y	N/A	Y	N/A	N/A
Have you had problems with working?	N	Y	N	N	Y	Y	Y	Y	Y	Y	Y	Y
Sand/Gravel Slurry	N	N	N	N	N	N	N	N	N	N	N	N
Does it work?	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
How often?	N	N	N	N	N	N	N	N	N	N	N	N
Cost of Material?	N/A	\$30.00	N/A	N/A	\$60.00	N/A	\$150.00	N/A	\$150.00	N/A	N/A	N/A
Do you make the drains?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Does it work?	N/A	Y	N/A	Y	Y	Y	Y	Y	Y	Y	Y	Y
Compacted Soil	Some	Y	Some	Some	Y	Y	Y	Y	Some	Y	Some	Some
Does it work?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Has in-situ material ever been replaced?	Y	Y	Y	N	N	N	N	N	N	N	N	N
Reinforced	Y	Y	Y	N	N	N	N	N	N	N	N	N
Does Reinforced backfill cause problems?	Y	Y	Y	N	N	N	N	N	N	N	N	N
Preferred Backfill Material?	Stone	Flowable Fill	Granular	Granular	Granular	Granular	Granular	Granular	Granular	Granular	Granular	Granular
Would like to try new materials?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Is there a major problem?

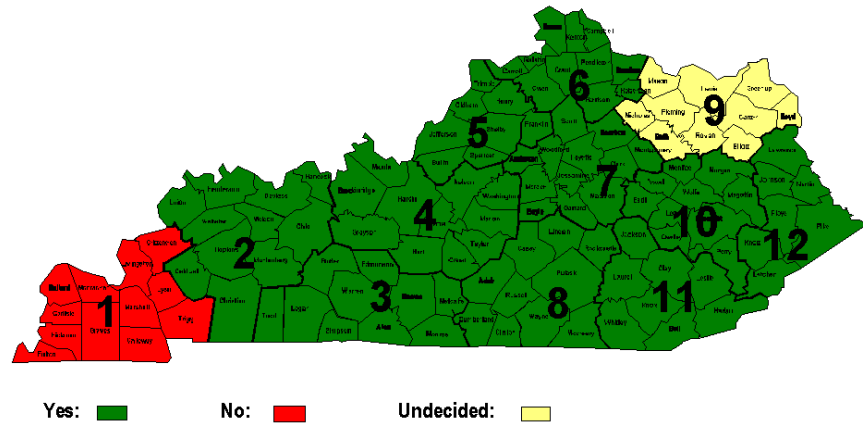


Figure 1: Is there a major problem?

Is settlement uniform across roadway?

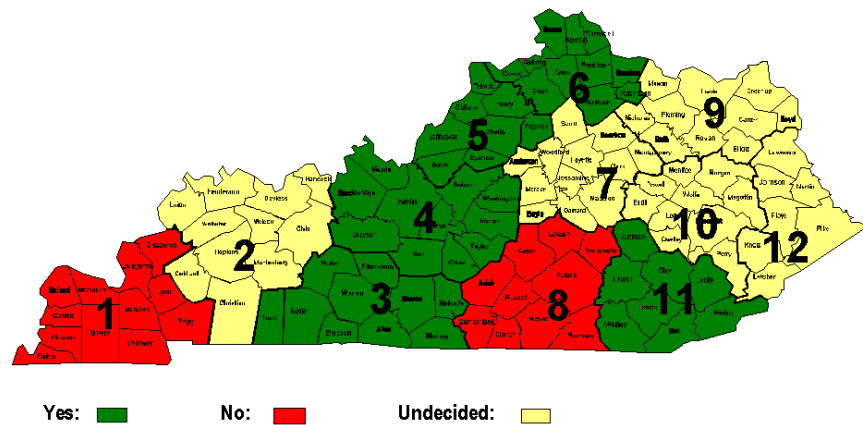


Figure 2: Is settlement uniform across roadway?

Does fill/native soil settling cause problems?

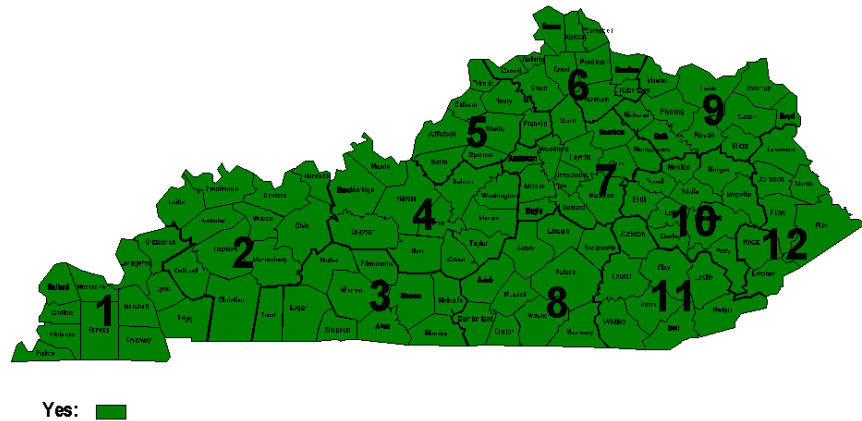


Figure 3: Does fill/native soil settling cause problems?

Do fills getting larger and larger, higher cause problems?

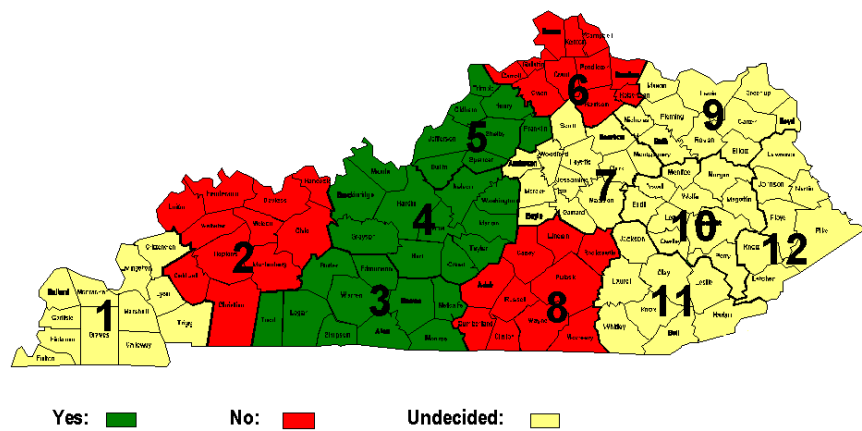


Figure 4: Do fills getting larger and larger, higher cause problems?

Yes: ■ No: ■ Undecided: ■

**Figure 5: Do backfill materials settling cause problems?**

### Figure 6: Does poor compaction cause problems?

Are there any contractor-construction related problems?

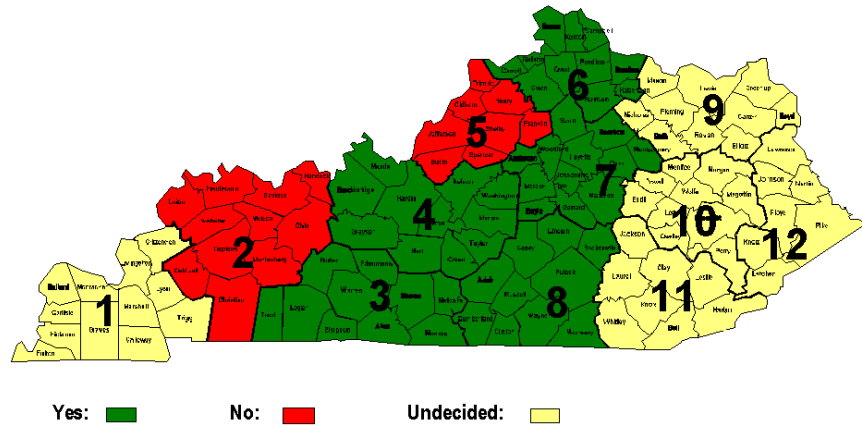


Figure 7: Are there any contractor-construction related problems?

Does the movement of a structure itself, turned on a weak axis, cause problems?

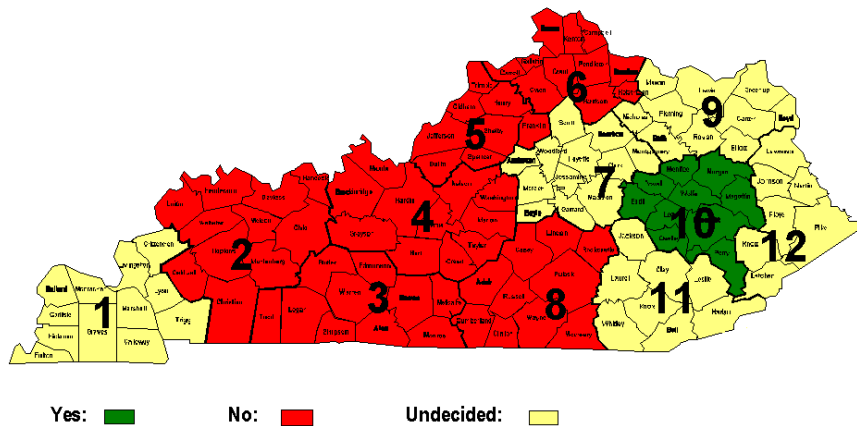


Figure 8: Does the movement of a structure itself, turned on a weak axis, cause problems?

nr



Does expansion and contraction cause problems?

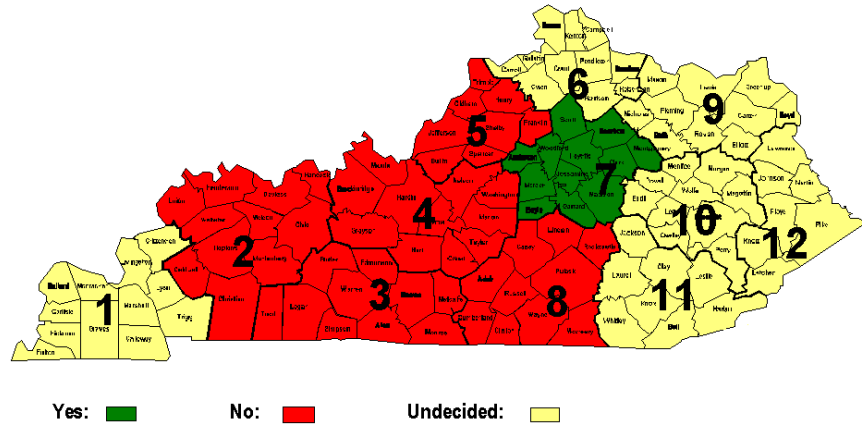


Figure 9: Does expansion and contraction cause problems?

Does your district have any input into the design?

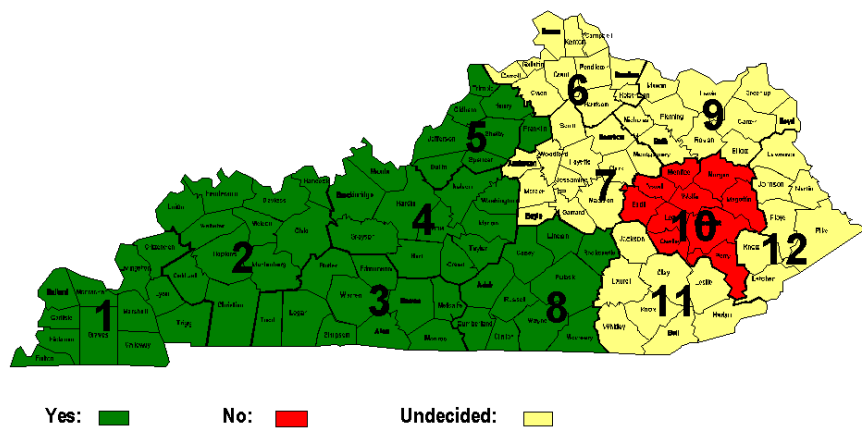
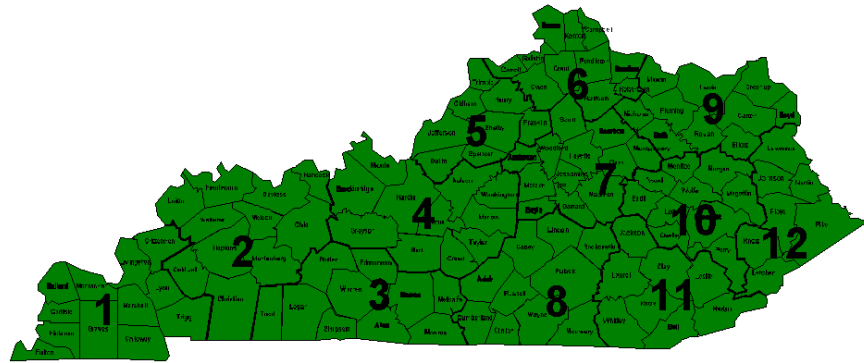


Figure 10: Does your district have any input into the design?

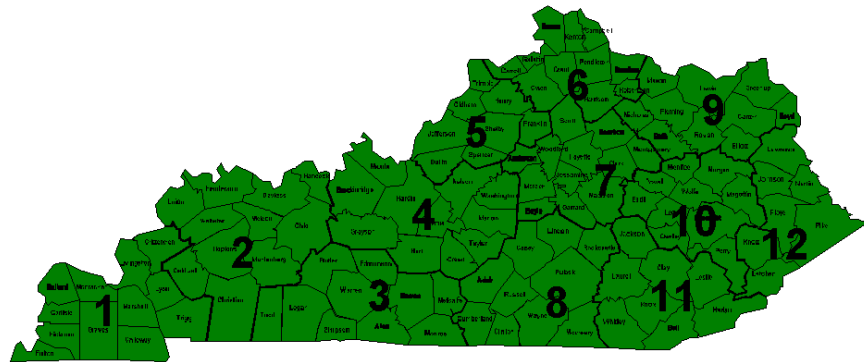
Reinforced Approach Slabs - Do you use them?



Yes: 

Figure 11: Reinforced Approach Slabs – Do you use them?

Integral End-Bents - Do you use them?



Yes: 

Figure 12: Integral End-Bents – Do you use them?

Abutments - Do you use them?

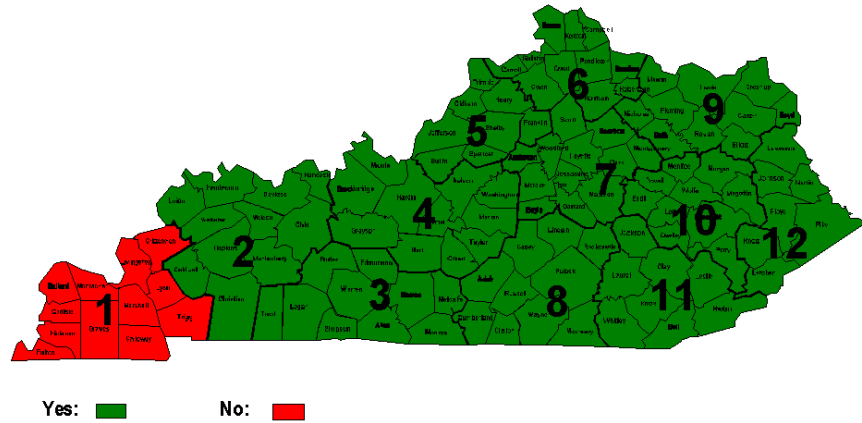


Figure 13: Abutments – Do you use them?

Abutments with spread footer - Do you use them?

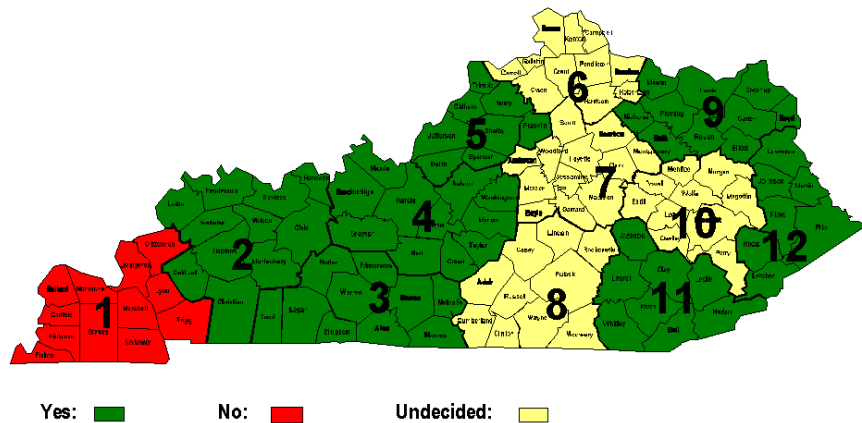
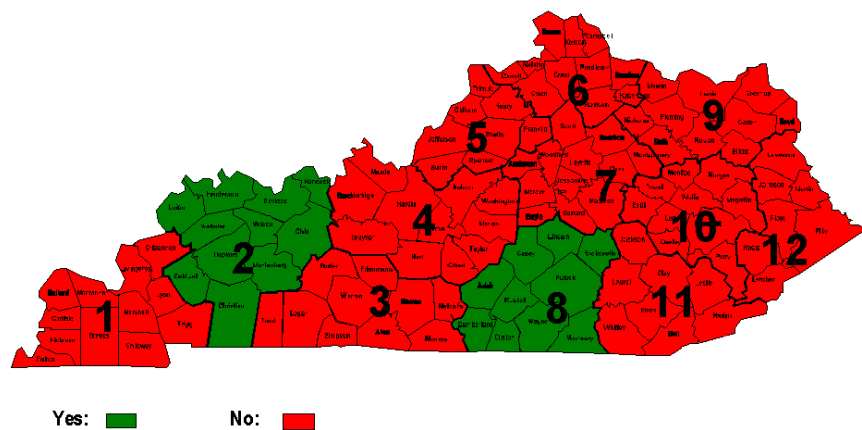


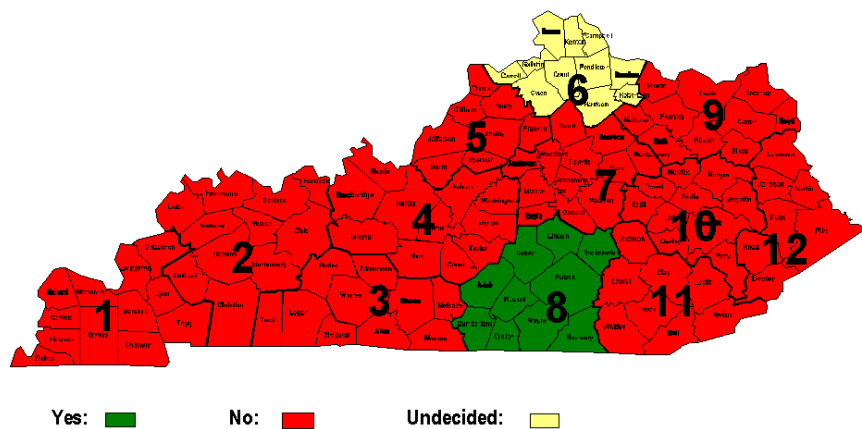
Figure 14: Abutments with spread footer – Do you use them?

Sleeper Slabs - Do you use them?



**Figure 15: Sleeper Slabs – Do you use them?**

Are you surcharging the last ten years as a prevention technique?



**Figure 16: Are you surcharging the last ten years as a prevention technique?**

**Yes:** ■ **No:** ■

**Figure 17: Do you have a waiting period (Fill) as a prevention technique?**

**Yes:** ■      **No:** ■      **Undecided:** ■

**Figure 18: Do you place the approach slab below grade as a prevention technique?**

Should wing walls be brought back as a prevention technique?

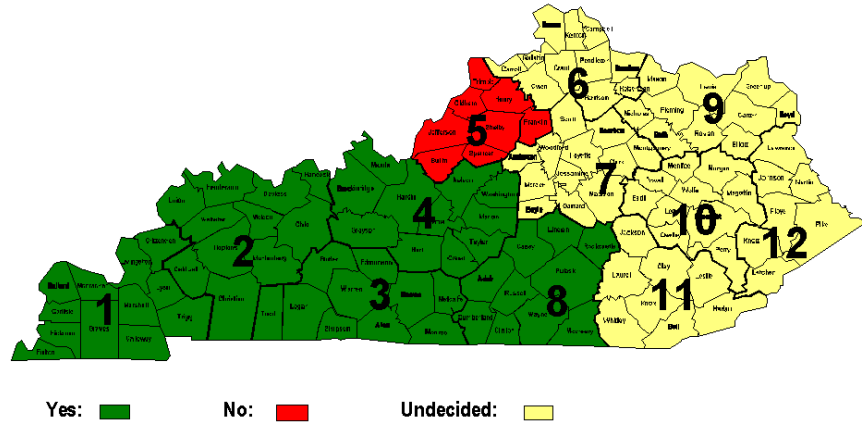


Figure 19: Should wing walls be brought back as a prevention technique?

Do you use Earth Walls (MSE) as a prevention technique?

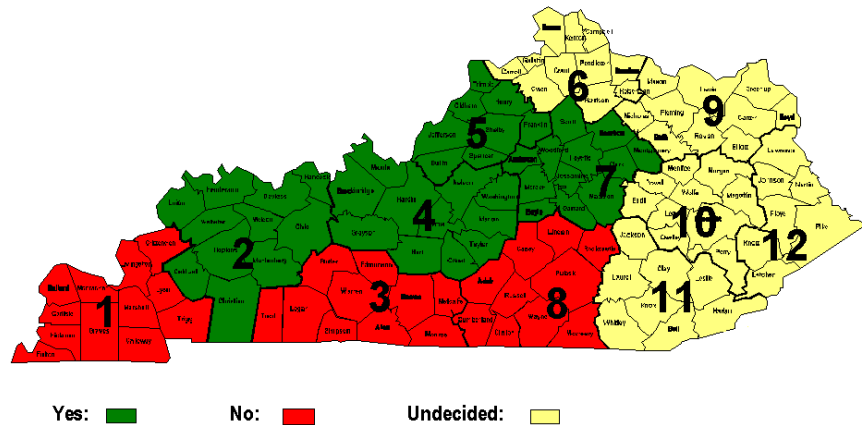


Figure 20: Do you use Earth Walls (MSE) as a prevention technique?

Do you run densities on embankment and approach as a prevention technique?

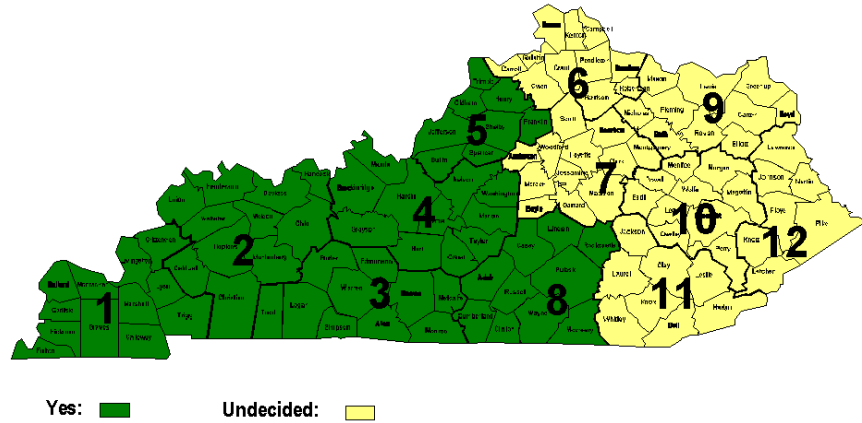


Figure 21: Do you run densities on embankment and approach as a prevention technique?

Do you pave over bridges as a prevention technique?

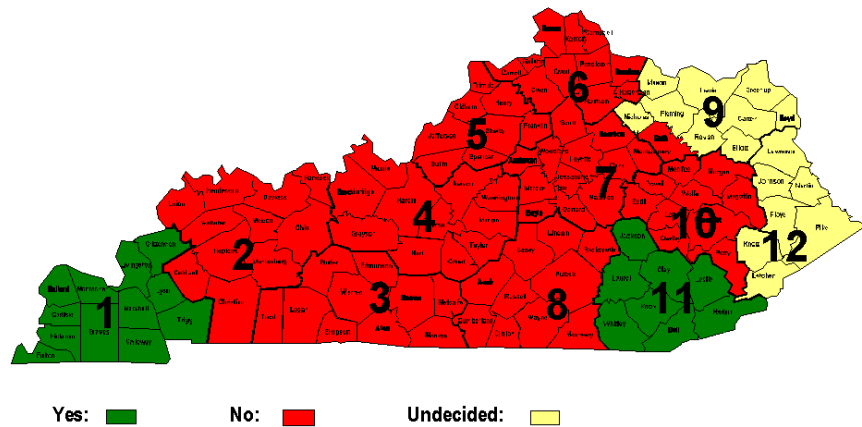


Figure 22: Do you pave over bridges as a prevention technique?

Do you do a lot of maintenance?

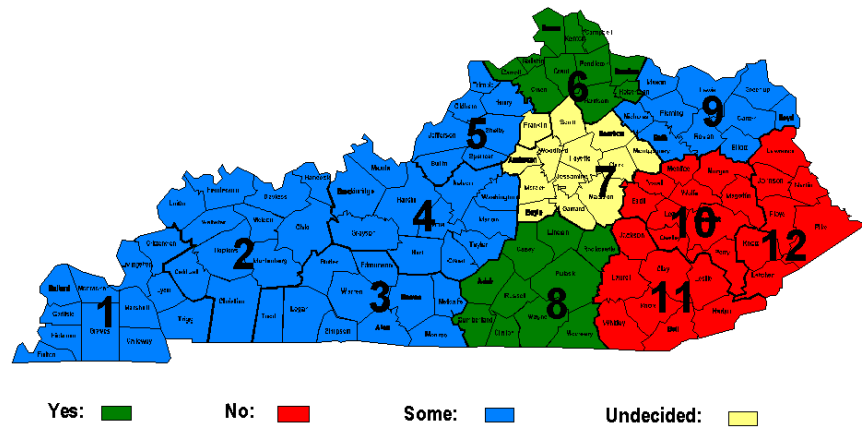


Figure 23: Do you do a lot of maintenance?

Do you use mud jacking/slab jacking as a maintenance procedure?

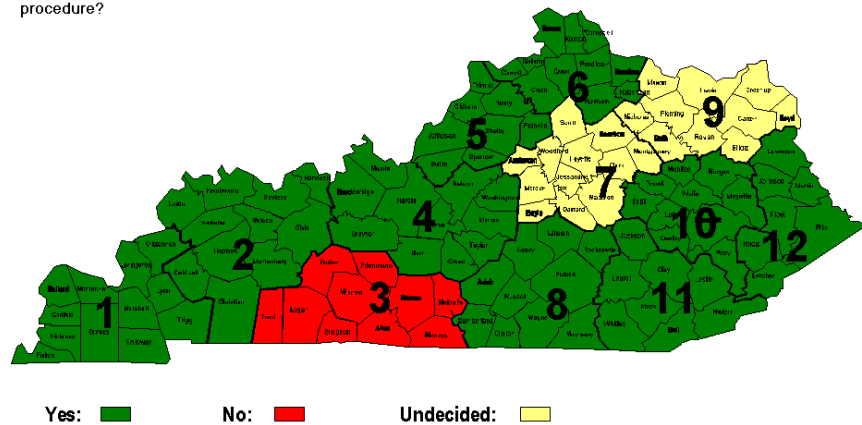


Figure 24: Do you use mud jacking/slab jacking as a maintenance procedure?



Do you use foam injection as a maintenance procedure?

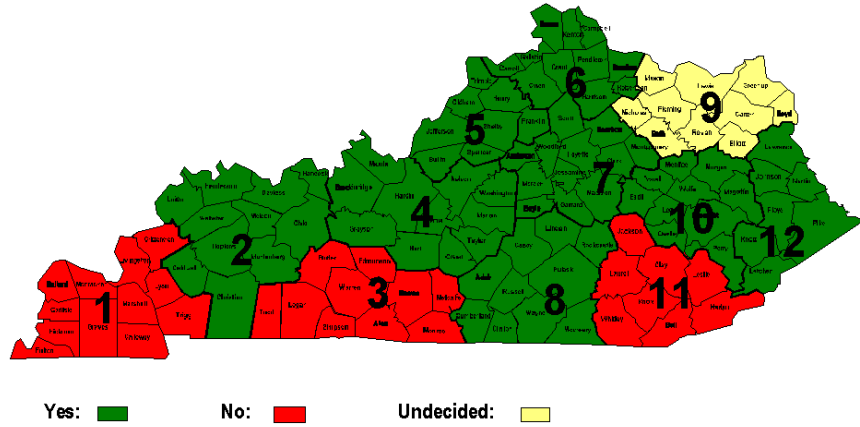


Figure 25: Do you use foam injection as a maintenance procedure?

Do you use sand injection/sand slurry in maintenance procedures?

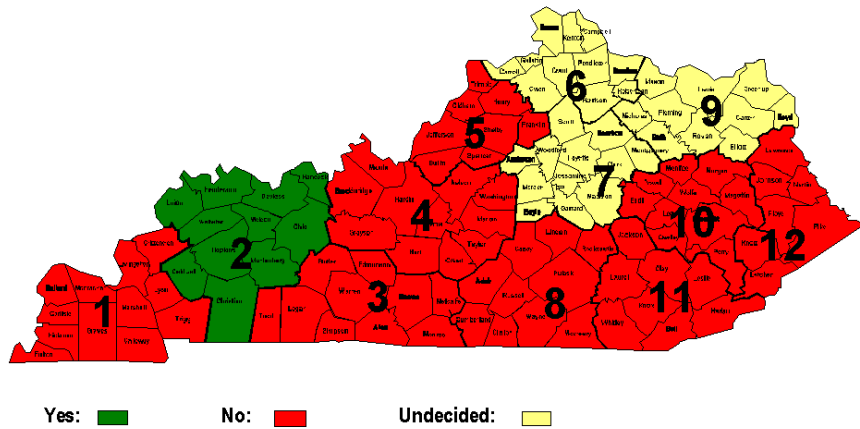
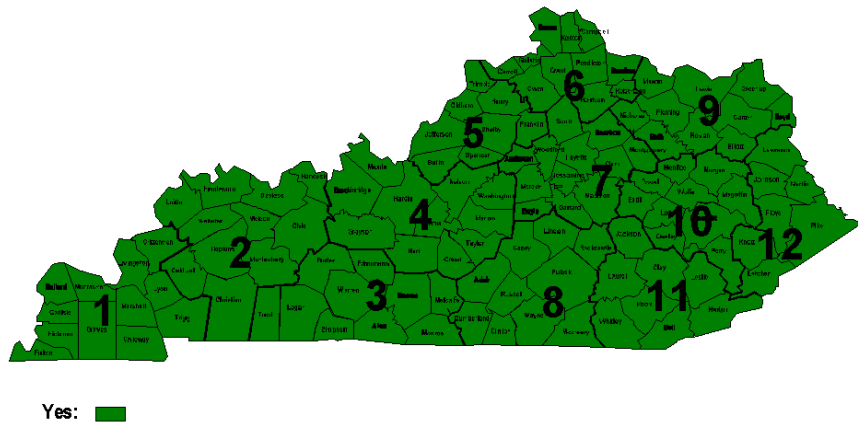


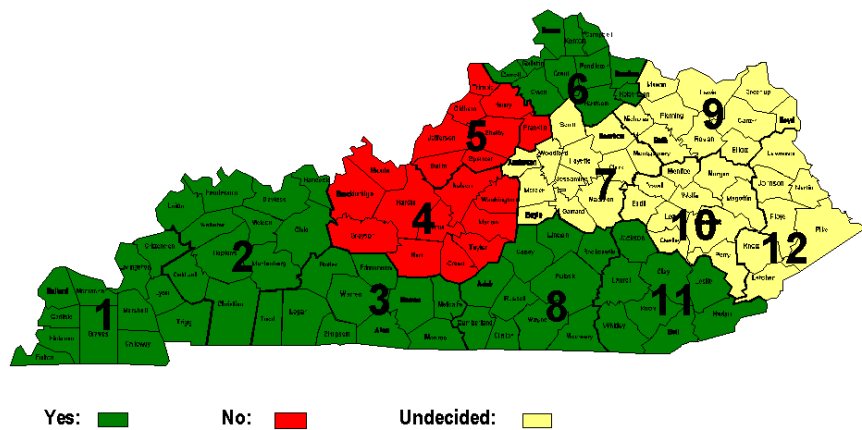
Figure 26: Do you use sand injection/sand slurry in maintenance procedure?

Do you use wedging as a maintenance procedure?



**Figure 27: Do you use wedging as a maintenance procedure?**

Do you mill and replace as a maintenance procedure?



**Figure 28: Do you mill and replace as a maintenance procedure?**

Total estimated cost (1 bridge end)? Paving whole

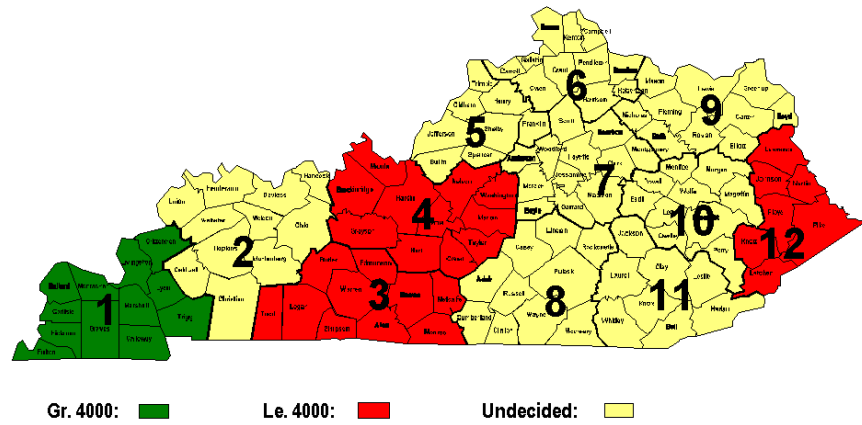


Figure 29: Total estimated cost (1 bridge end)? Paving Whole

What length?

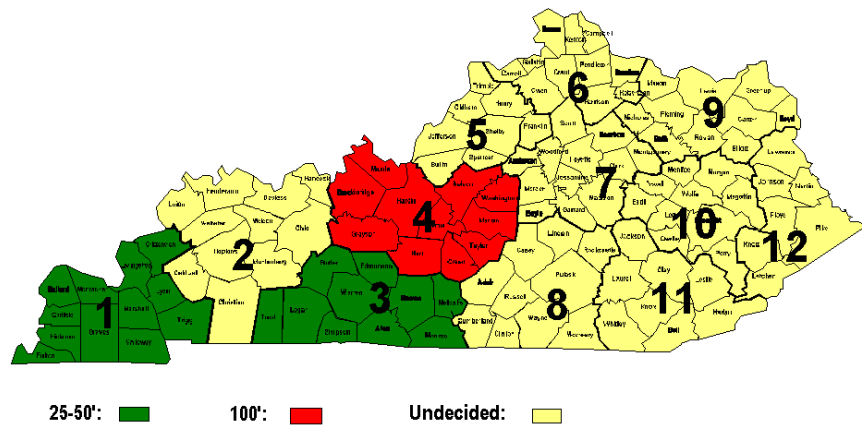


Figure 30: What length?

Do you use 4" perforated pipe?

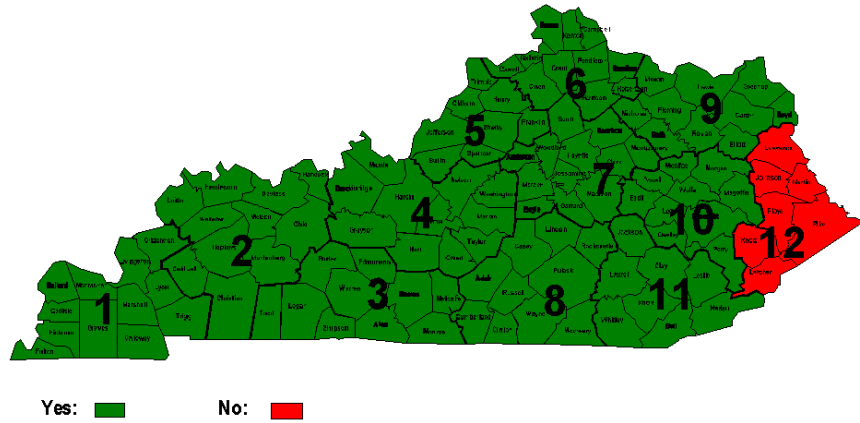


Figure 31: Do you use 4" perforated pipe?

Do you use 6 " perforated pipe?

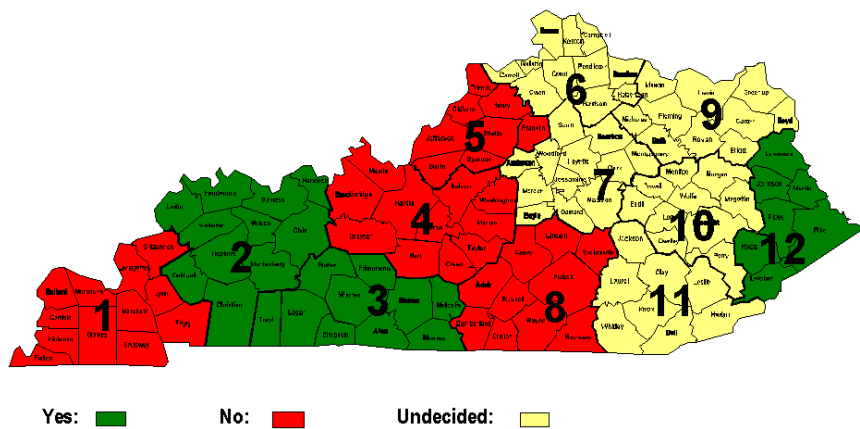


Figure 32: Do you use 6" perforated pipe?

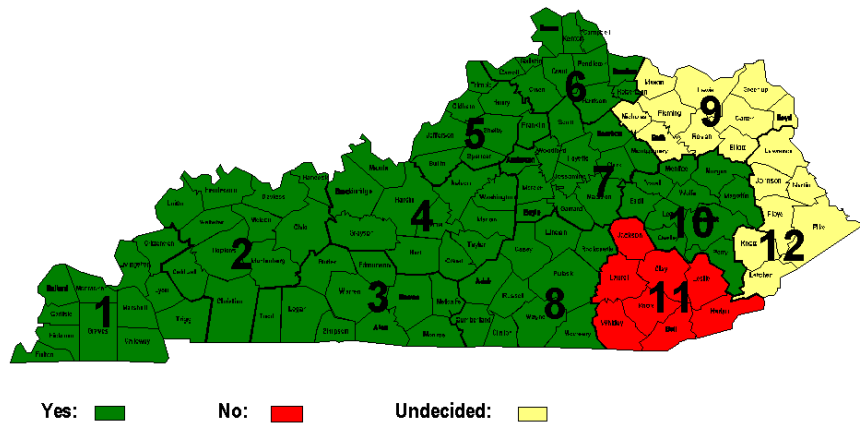
**Yes:** [Green Box]      **Undecided:** [Yellow Box]

### Figure 33: Do Weepholes work?

**Yes:** ■ **No:** ■ **Undecided:** ■

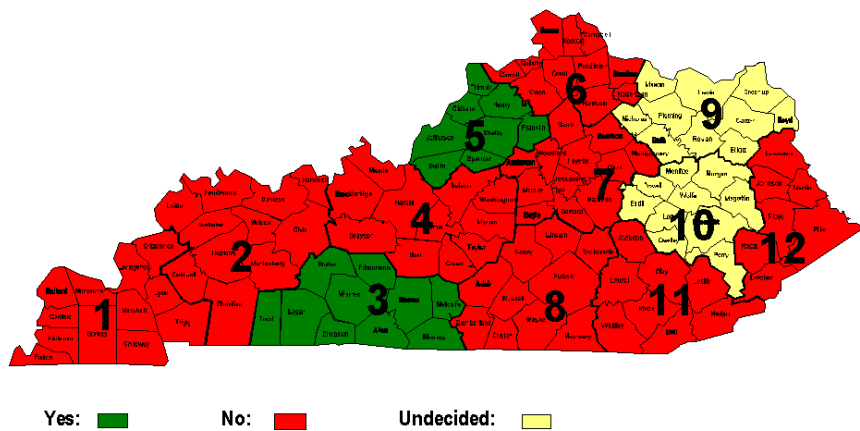
**Figure 34: Does edge drain around the perimeter of the pavement work?**

Outlet locations at bottom of slope?



**Figure 35: Outlet locations at bottom of slope?**

Paved ditches useful?



**Figure 36: Paved ditches useful?**

Do you use drainage blankets?

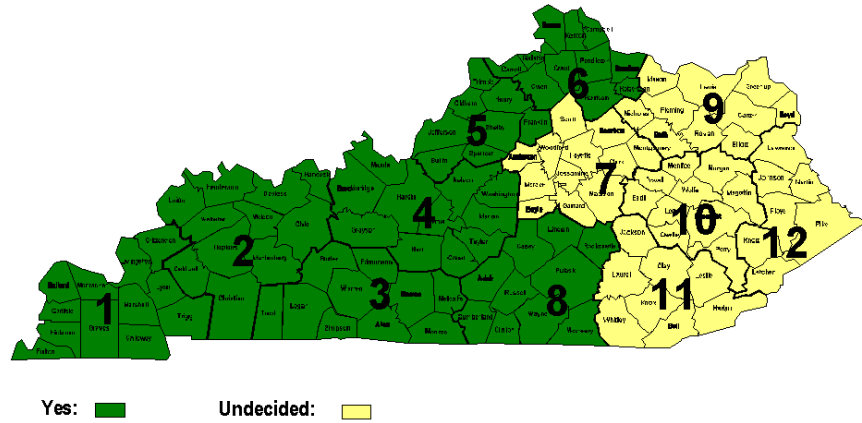


Figure 37: Do you use drainage blankets?

Is routine maintenance performed on the drainage system?

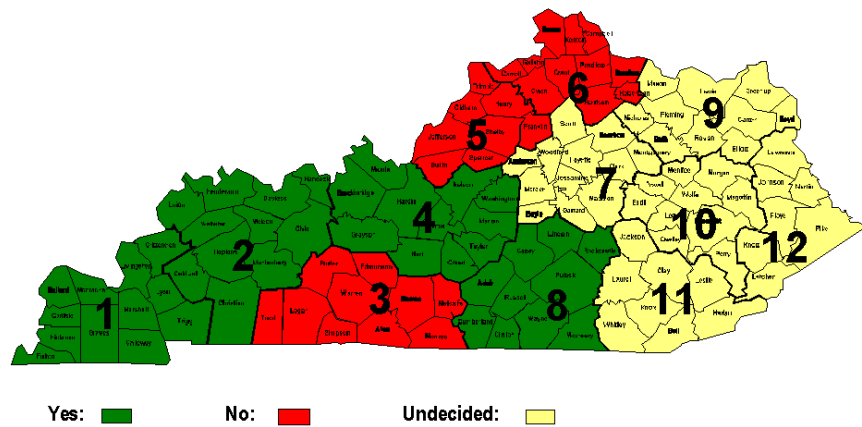


Figure 38: Is routine maintenance performed on the drainage system?

Do you think bridge end drainage is working?

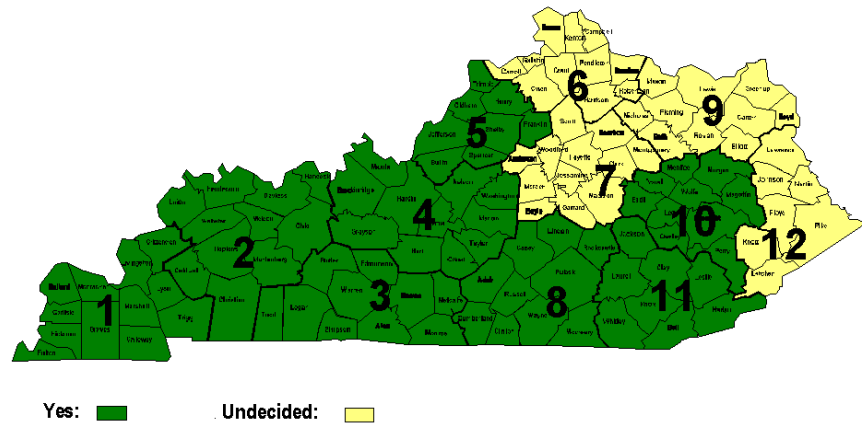


Figure 39: Do you think bridge end drainage is working?

Do you use granular number 57 backfill material?

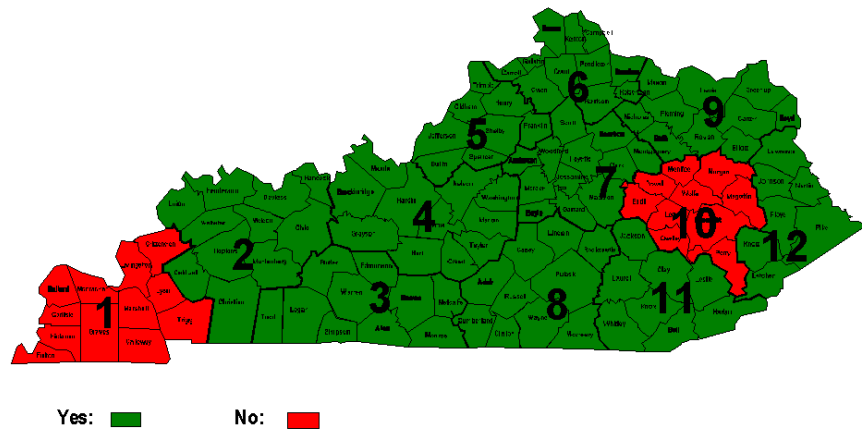


Figure 40: Do you use granular number 57 backfill material?



Do you use granular 2, wrapped or unwrapped?

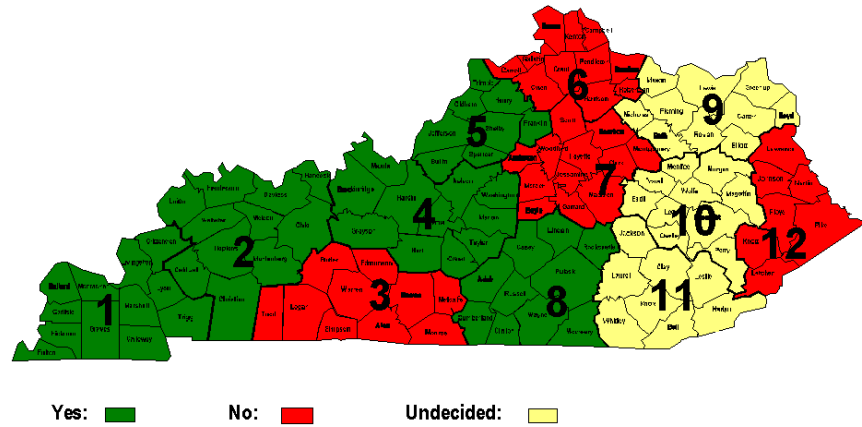


Figure 41: Do you use granular 2. Wrapped or unwrapped?

Do you use granular 2, choked w 57 unwrapped or wrapped?

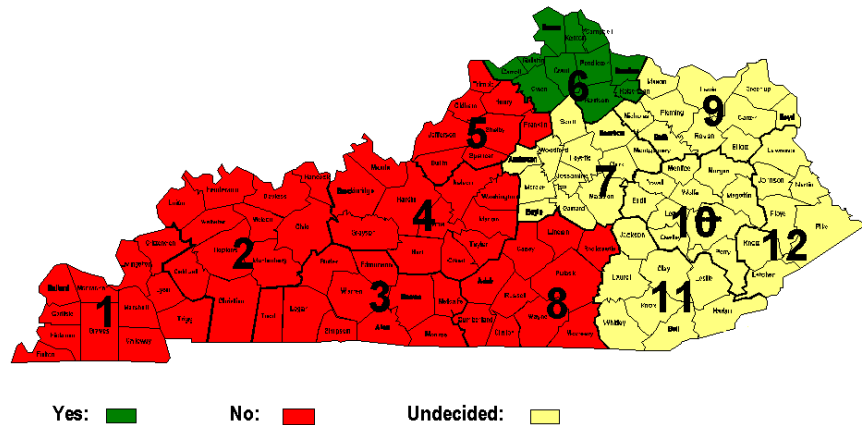


Figure 42: Do you use granular 2, choked w 57 unwrapped or wrapped?

Do you use granular 23 backfill material?

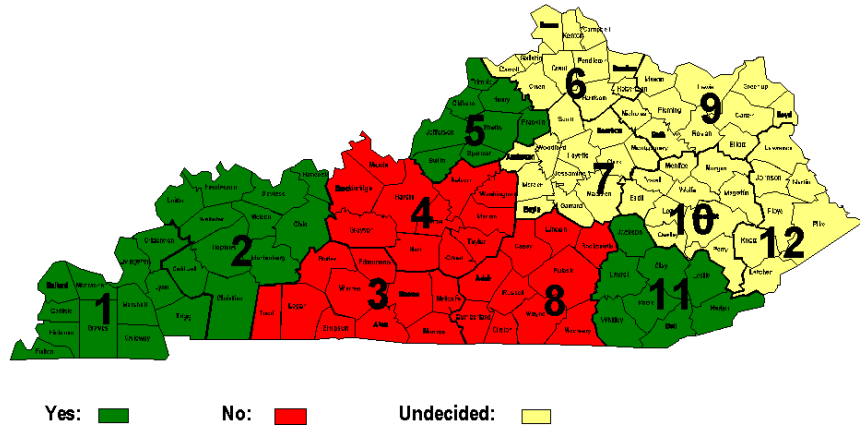


Figure 43: Do you use granular 23 backfill material?

Do you use granular 3 backfill material?

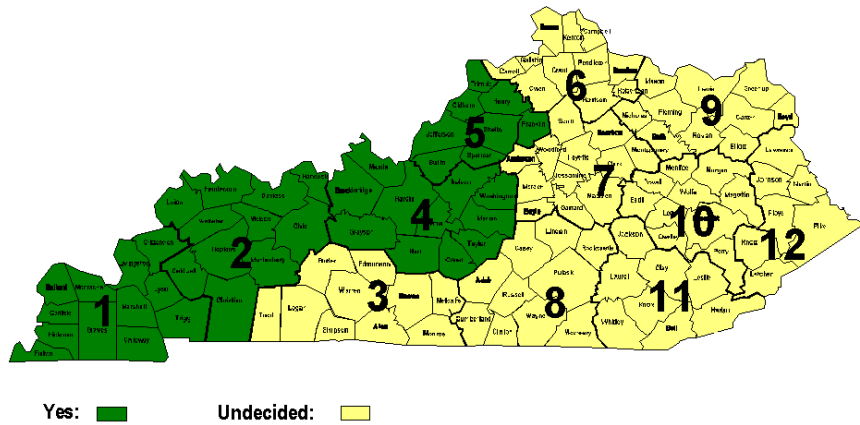


Figure 44: Do you use granular 3 backfill material?

Do you use granular 610 backfill material?

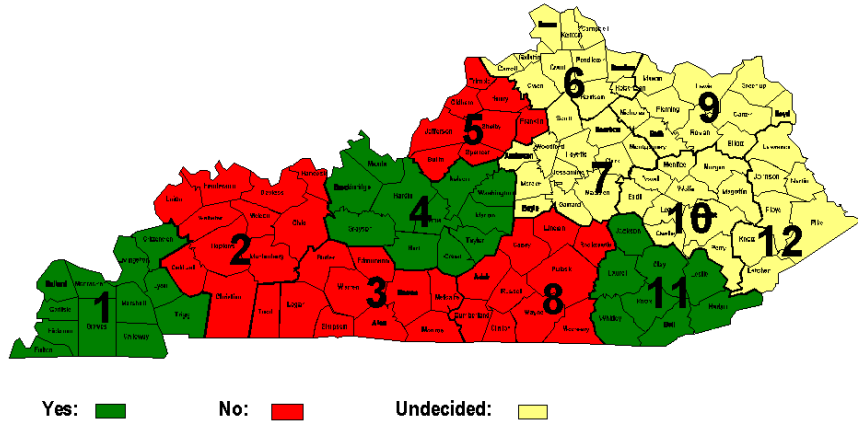


Figure 45: Do you use granular 610 backfill material?

Do you use granular 9 backfill material?

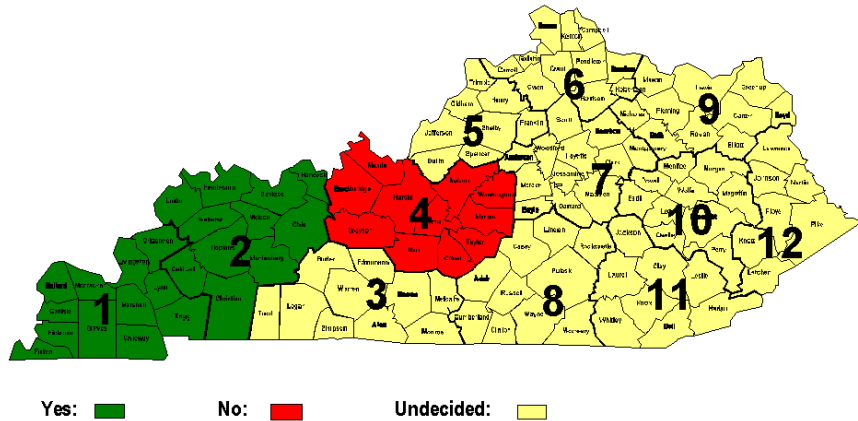


Figure 46: Do you use granular 9 backfill material?

**Figure 47: Do you use wrapping material – type 4 fabric?**

Yes: ■ No: ■ Undecided: ■

**Figure 48: Do you use sand/slurry as backfill material?**

Do you use flowable fill as backfill material?

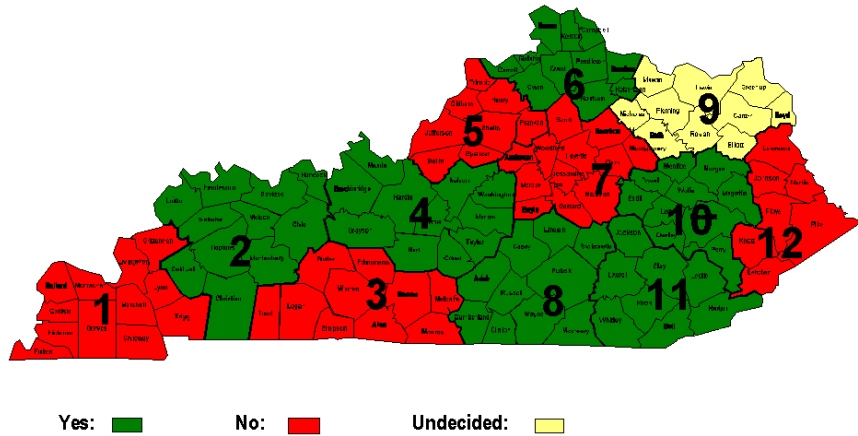


Figure 49: Do you use flowable fill as backfill material?

Do you use compacted soil as backfill material?

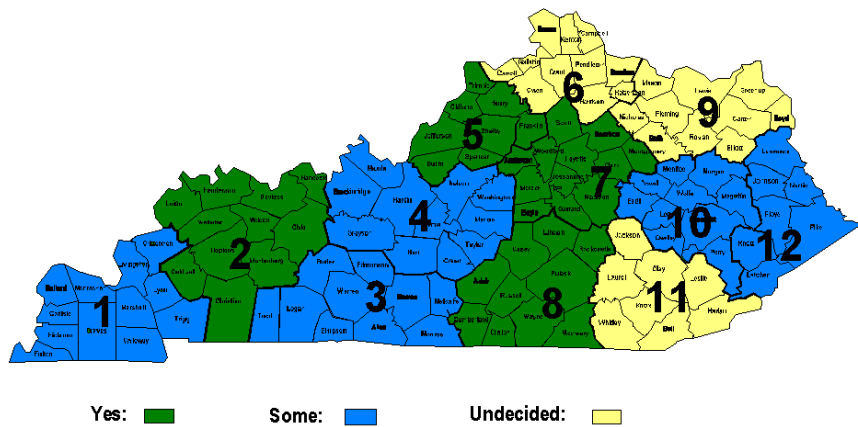


Figure 50: Do you use compacted soil as backfill material?

**Figure 51: Do you use river gravel as backfill material?**

**Figure 52: Does non-uniform backfill cause problems?**

Preferred backfill material?

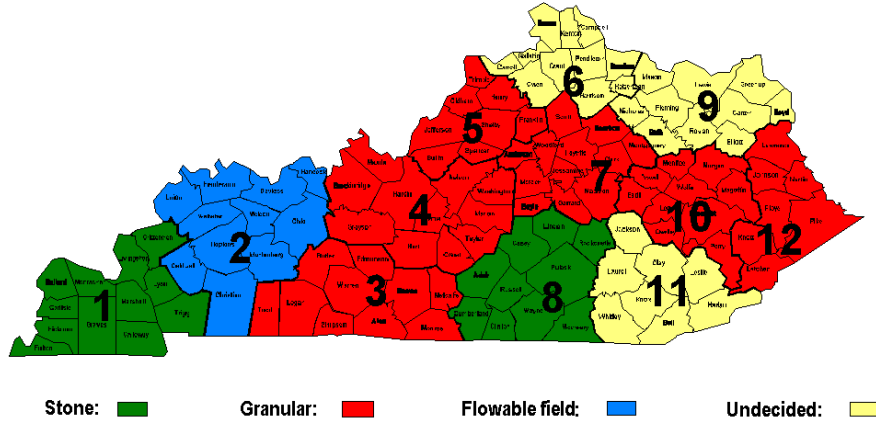


Figure 53: Preferred backfill material?

Would like to try new methods?

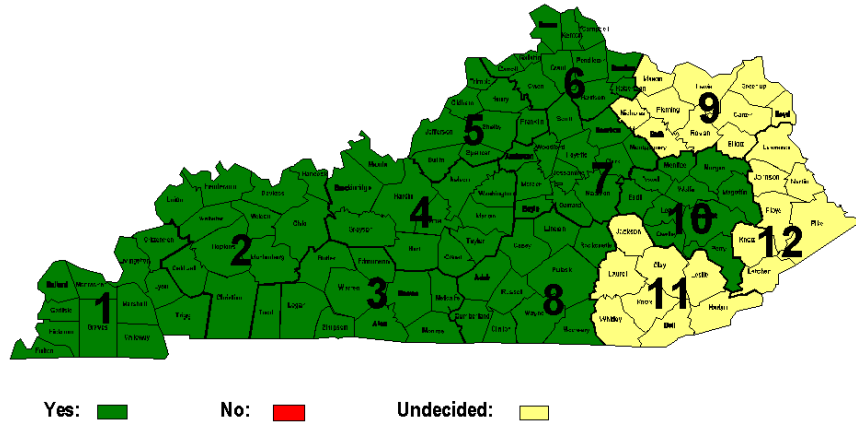


Figure 54: Would like to try new methods?